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Site investigation SFR

Drilling of water well HFR101 and monitoring wells HFR102 and HFR105

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September 2008

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Abstract

Three boreholes in solid rock, HFR101, HFR102 and HFR105, were drilled from the two piers at the Forsmark harbour, using percussion drilling technique. Borehole HFR101 was primarily aimed to characterize two minor lineaments, MFM3116G and MFM3117G, respectively, and also to be used as a pumping well for prospective planned interference tests. However, at 149.25 m length no water inflow was observed. The borehole was therefore extended to 209.30 m, aiming at penetrating the possible extension to the south of the sub-horizontal fracture zone ZFM871 (identified in connection with the pre-investigations and construction of the SFR-facilities and previously denominated zone H2). During the extended drilling, a groundwater inflow of 60 L/min was encountered between 150–200 m drilling length.

Borehole HFR101, which was drilled to 149.25 m during the period April 23rd to April 28th 2008 and extended to 209.30 m during May 14th and May15th 2008, is inclined c. 70° to the horizontal plane and has in its upper part a diameter of c. 139 mm.

Also borehole HFR102 was drilled with multiple objectives, firstly to investigate the possible existence of sub-horizontal fracture zones, secondly to explore a lineament denominated MFM3115G, and thirdly to be used as a monitoring well, enabling long-term study of ground water levels and groundwater-chemical composition. Borehole HFR102 was drilled during the period April 29th to May 5th 2008. The borehole is 55.04 m long, inclined 59° to the horizontal plane and is drilled with a diameter of approximately 138 mm (in the upper part). No measurable inflow was encountered, but several days after completed drilling, the groundwater table had recovered and was stabilized equal to the sea–level.

HFR105 was drilled for two purposes, firstly to investigate lineament MFM1032G and secondly to be used for monitoring groundwater levels and the groundwater-chemical composition. Borehole HFR105 was drilled during the period April 15th to April 22nd 2008. The borehole is 200.50 m long and inclined 62° to the horizontal plane and has a diameter of about 141 mm in the upper part. A groundwater inflow of 64 L/min was encountered between 121–200 m during drilling.

Sammanfattning

Tre hammarborrhål, HFR101, HFR102 och HFR105, har borrats på pirerna intill hamnområdet vid Forsmarks hamn. Borrhål HFR101 var tänkt att dels karaktärisera två mindre lineament, benämnda MFM3116G respektive MFM3117G, dels att användas som pumpbrunn vid kommande interferenstester. Då emellertid inget vatten påträffats vid 149 m borrlängd förlängdes borrhålet i syfte att genomkorsa den eventuella fortsättningen mot söder av den flacka sprickzonen ZFM871, som identifierades i samband med förundersökningarna inför och bygget av SFR-anläggningen, och som då benämndes zon H2.

HFR101 borrades under perioden 23–28:e april 2008 till ca 149 m, och förlängdes mellan 14:e och 15:e maj 2008. Borrhålet är 209,30 m långt, är ansatt ca 70° mot horisontalplanet och är borrat med startdiametern 139 mm. Under förlängningen av borrhålet noterades ett grundvatteninflöde av ca 60 L/min mellan 150–200 m.

HFR102 borrades under perioden 29:e april till den 5:e maj 2008. Borrhålet utfördes med tre syften, för det första att undersöka den eventuella förekomsten av sub-horisontella sprickzoner, för det andra att penetrera lineamentet MFM3115G samt, för det tredje, att användas som observationsbrunn för monitering av grundvattennivån vid såväl ostörda som störda (t ex vid pumptester) förhållanden och för grundvattenkemisk provtagning. Borrhålet är 55,04 m långt, är ansatt ca 59° mot horisontalplanet samt är borrat med startdiametern 138 mm. Under borrningen noterades inga inflöden, men flera dagar efter avslutad borrning hade borrhålet vattenfyllts och grundvattenytan stabiliserats vid samma nivå som havsnivån.

HFR105 borrades under perioden 15–22:a april 2008 till 200,50 m. Borrhålet utfördes med två syften, dels att undersöka lineamentet MFM1032G, dels för att användas som moniteringsbrunn både vid störda och ostörda förhållanden. Borrhålet är ansatt ca 62° mot horisontalplanet och är borrat med startdiametern 141 mm. Under borrningen noterades ett inflöde om ca 54 L/min vid ca 121 m borrlängd, medan borrhålet vid fullt djup gav 64 L/min.

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1 Introduction

The Swedish Nuclear Fuel and Waste Management Co (SKB) is since the mid 80-ies running the underground final repository for low- and medium level radioactive operational waste (SFR) at Forsmark within the Östhammar municipality, see Figure 1-1. Since April 2008, SKB conducts bedrock investigations for a future extension of the repository. The extension project, in Swedish termed "Projekt SFR-utbyggnad" (Project SFR Extension), is organized into a number of sub-projects, of which geoscientific investigations are included in one sub-project, "Projekt SFR-utbyggnad – Undersökningar" (Project SFR Extension – Investigations).

Figure 1-1. *General overview over Forsmark and the SFR site investigation area.*

The geoscientific investigations for the planned extension of SFR are performed in compliance with an investigation programme /1/. Experience and data from the construction of the existing SFR facility in the 1980-ies served as important input for the programme. Further, the recently completed comprehensive site investigations for a final repository for spent nuclear high-level waste at Forsmark (controlled by a general investigation programme, /2/), provided a vast amount of data about the sub-surface realm down to about 1,000 m in the immediate vicinity of, and even overlapping, the SFR-area. Data and experiences also from these investigations have strongly influenced the elaboration of investigation strategies for the current SFR-investigation programme.

For direct sub-surface investigations, drilling is an inevitable activity. Providing investigation boreholes is especially vital in the SFR-project, because the major part of the rock volume to be investigated is covered by the Baltic Sea, thereby rendering ground geophysical measurements and other surface-based investigations more difficult than at land. Two main types of boreholes will be produced within the scope of the site investigations, core drilled- and percussion drilled boreholes, respectively. For the initial phase of the investigations five percussion-drilled and five core-drilled boreholes from the ground surface and one core-drilled borehole drilled underground from the SFR facility have been suggested /1/.

This document reports the results gained by drilling three percussion boreholes, HFR01, HFR02 and HFR05 from the piers at the Forsmark harbour, which is the initial investigation activity of Project SFR Extension – Investigations. The activity was carried out in accordance with Activity Plan AP SFR-08-001. The controlling documents for performing this activity are listed in Table 1-1. Both activity plan and method descriptions are SKB’s internal controlling documents.

New drill sites for five cored boreholes were built on the pier at Asphällskulten during the spring 2008, see Figure 1-2. In addition, an old borehole drilled 1985, KFR27, was rediscovered, although the borehole casing was covered with gravel one metre below ground surface. As KFR27 will be restored, also a minor drill site was prepared around the casing of this borehole. The percussion boreholes HFM01 and HFM02 were drilled from the Asphällskulten pier, whereas HFM105 was drilled from the jetty more close to the Forsmark harbour (see Figure 1-2).

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

Drilling and measurements while drilling were carried out during the period April 15th to April 28th 2008 (HFR10), after which the borehole was extended during May 14th and May15th 2008, April 29th to May 5th 2008 (HFR102), and April 15th to April 22nd 2008 (HFM05).

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

Activity plan	Number	Version
Hammarborrning av borrhål HFR101, HFR102 and HFR105.	AP SFR -08-001	1.0
Method descriptions	**Number**	**Version**
Metodinstruktion för utsättning och ansättning av hammar- och kärnborrhål.	SKB MD 600.002	1.0
Metodbeskrivning för hammarborrning.	SKB MD 610.003	4.0
Metodinstruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning.	SKB MD 600.004	1.0
Metodinstruktion för användning av kemiska produkter och material vid borrning och undersökningar.	SKB MD 600.006	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	3.0

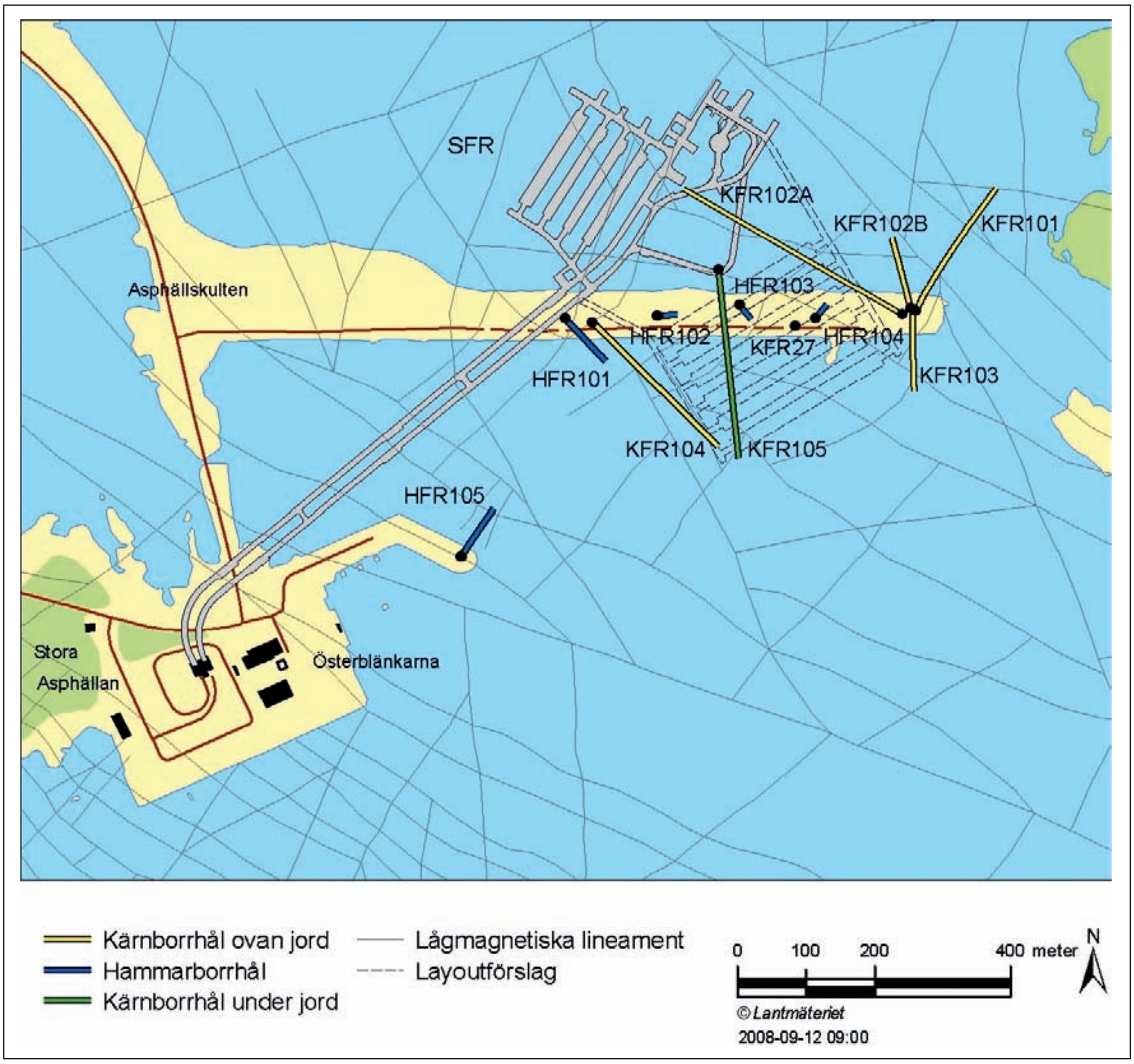


Figure 1-2. *Overview over the SFR site investigation area, with existing and planned boreholes and the candidate area for the SFR extension marked with lines.*

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the Activity Plan number (AP SFR-08-001). 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 also entail a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

2 Objective and scope

Percussion borehole HFR101 was expected to provide a sufficient water yield to serve as pumping well for future interference tests. Secondly, the borehole was aimed to characterize two minor lineaments denominated MFM3116G and MFM3117G, respectively. However, at the planned full drilling length at about 149 m, no groundwater inflow whatsoever was observed. A decision was then made to extend the borehole sufficiently enough to render intersection of the possible extension to the south of the gently dipping fracture zone ZFM871 possible. Zone ZFM871 was identified in connection with the pre-investigations and construction of the SFR-facilities and was previously denominated Zone H2.

Also boreholes HFR102 and HFR105 were drilled with multiple aims. HFR102 was intended to explore possible sub-horizontal fracture zones in the upper bedrock, as well as to characterize the minor lineament MFM3115G, whereas HFR105 was intended to investigate the lineament MFM1032G. Both boreholes were also aimed to be used as monitoring wells, enabling long-term study of groundwater levels and groundwater-chemical composition.

All three boreholes HFR101, HFR102 and HFR105 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 characterised, another criterion for determining strike and dip of especially boreholes HFR102 and HFR105 was to locate them within the expected radius of influence of groundwater-level drawdown during the planned core drilling, both from the pier at Asphällskulten and from underground in the SFR-facility.

After completion of drilling and borehole investigations, the boreholes discussed in this report will be used for long-term groundwater level monitoring and groundwater sampling. Data gained during monitoring of undisturbed groundwater levels in the above mentioned boreholes is part of the characterization of the groundwater conditions of the shallow part of the bedrock. Monitoring during the percussion and, later, core drilling operations at the pier at Asphällskulten, i.e. at stressed conditions, is primarily part of the environmental control program for the drilling operations. However, also these data may be used for basic hydraulic characterization.

3 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.

3.1 Drilling system

A Nemek 407 RE drilling machine was employed for the commission of drilling the three boreholes HFR101, HFR102 and HFR105, see Figure 3-1. This type of machine is equipped with separate engines for transportation and power supplies. Water and drill cuttings were discharged from the boreholes 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 (Down The Hole)-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, designed for pre-drilling c. 10 m into low fractured rock, which has been an often used length for casing driving in SKB investigation boreholes.

Figure 3-1. The Nemek 407 RE percussion drilling machine employed for drilling the percussion boreholes HFR101, HFR102 and HFR105. As the boreholes are of chemical type, all DTH-equipment was cleaned on-site with hot water.

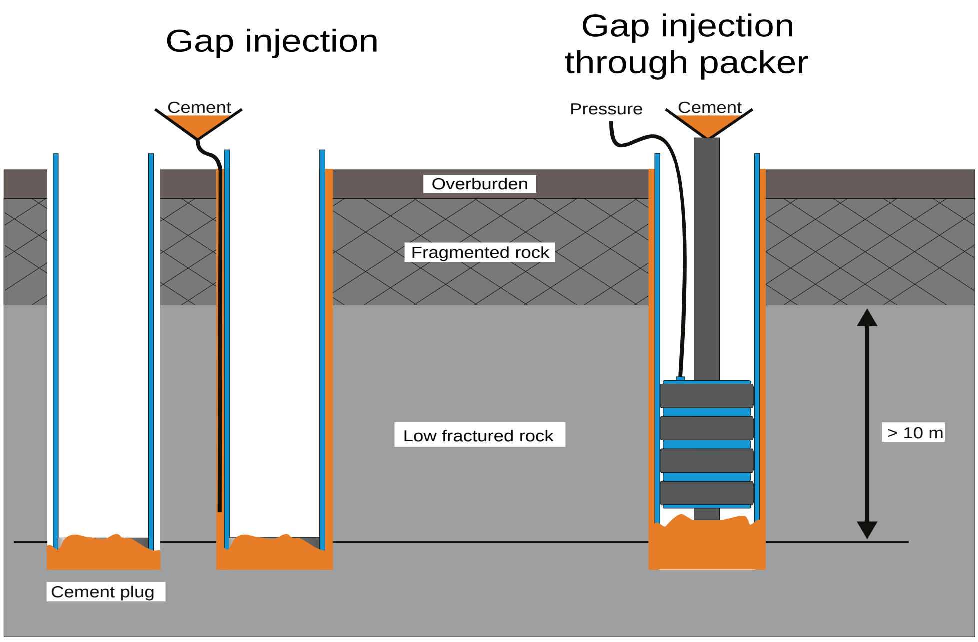


Figure 3-2. *Examples of gap injection technique. In order to grout the gap between the borehole wall and the casing, different systems may be used. To the left, filling up a cement-water mixture with a flexible hose is shown. To the right, injection is performed through a borehole packer. However, in the present activity, a third technique was applied, see description in text.*

In order to achieve geotechnical knowledge from the upper bedrock just under the overburden, the pre-drilling and casings in the percussion boreholes HFR101, HFR102 and HFR105 were limited to only c. 1 m into firm bedrock, implying a different grouting technique to be used compared to those illustrated in Figure 3-2. A mixture of cement, salt and water was squeezed to balls with the size of tennis balls and dropped into the borehole. Thereafter the casing was pressed through the grout and into the borehole bottom.

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.

3.4 Equipment for measurements and sampling during drilling

A number of measurements were performed while drilling each of the three boreholes, see Figure 3-3. 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 Yokogawa Mod SE72 field measuring devise. This instrument was calibrated before use according to standards.

Figure 3-3. *To the left, drilling penetration rate is manually measured with a stop watch, and to the right drill cuttings are sampled in a bucket of stain-less steel before placed in labeled pots.*

4 Execution

4.1 General

Drilling of boreholes HFR101, HFR102 and HFR105 followed SKB MD 610.003, (Latest version of "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.

4.2 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, ("Method Instruction for Chemical Products and Materials"). Finally, the down-hole part of the equipment was cleaned in accordance with SKB MD 600.004, ("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.

4.3 Drilling and measurements during drilling of borehole HFR101, HFR102 and HFR105

A TUBEX-system (an ODEX-variant) was applied for drilling through the overburden and c. 1 metre 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 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

The special technique applied in this activity for grouting the casings in boreholes HFR101, HFR102 and HFR105 was described in Section 3.2.

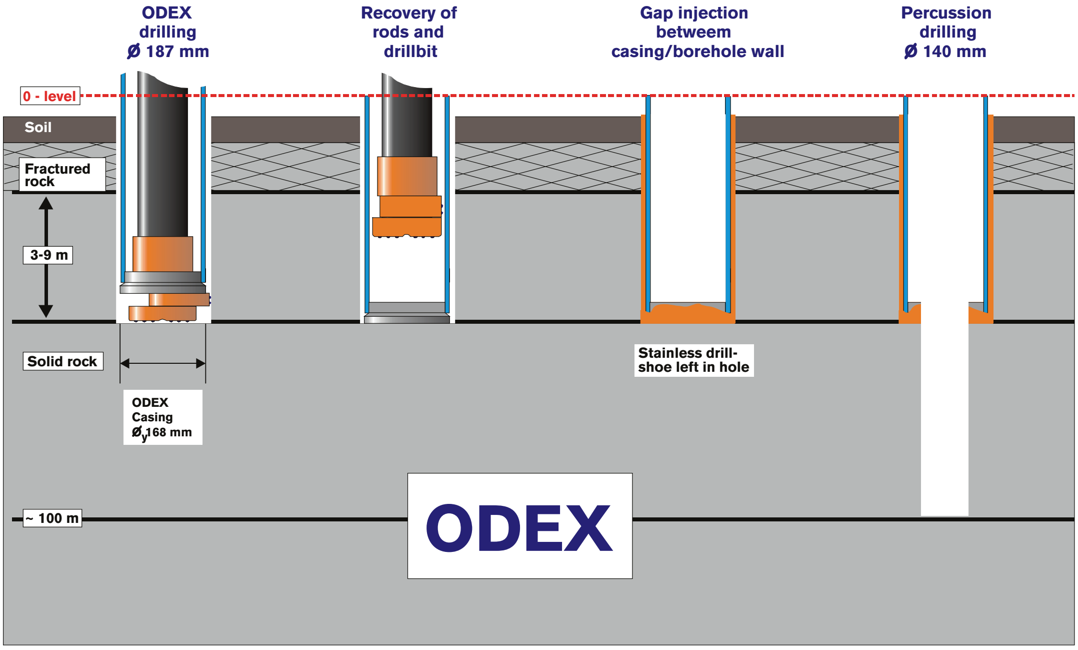


Figure 4-1. The different steps included in the performance of the percussion drilled boreholes HFR101, HFR102 and HFR105. In order to achieve geotechnical knowledge from the upper bedrock just under the overburden, the pre-drilling and casings were limited to only c. 1 m into firm bedrock, implying a different grouting technique to be used compared to those illustrated in this figure. A mixture of cement, salt and water was squeezed to balls with the size of tennis balls and dropped into the borehole. Thereafter the casing was pressed through the grout and into the borehole bottom.

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. 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 SFR, and when drilling long boreholes the drill bit has to be grinded. Also the initial diameter of boreholes HFR101 and HFR102 is slightly less than 140 mm because drilling started with a slightly worn drill bit.

4.3.4 Sampling and measurements during drilling

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

- Collecting one soil sample per metre drilling length. Analysis and results will be reported separately.
- Collecting one sample per 3 metres drilling length of drill cuttings from the bedrock. Each major sample consists of three individual minor samples collected at every metre borehole length, stored in one plastic box marked with a sample number. As far as possible, mixing of the three individual samples was avoided. A first description of the material was made on-site including the mineral content and rock structure, which gave a preliminary classification of the rock type. These samples were later examined more thoroughly and interpreted together with a BIPS-log (so called Boremap mapping) /3/. The results will be reported elsewhere.
- 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 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.

4.4 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 Deviation measurements

A short time after completed drilling, deviation measurements were carried out with the FLEXIT Smart Tool System. The deviation measurements in all three boreholes were carried out at every 3 m, both downwards and upwards. The quality control program of deviation measurements is mostly concentrated to the handling of the instrument as well as to routines applied for the performance. However, it is normally not possible to “calibrate” the deviation measurement instrument, as no boreholes with access to both the borehole collar and the borehole end are available. Instead, deviation measurements should always be performed at least twice. In the present case one survey was conducted in HFR101 to 147 m drilling length and four surveys to full borehole length, 207 m (after extension of the borehole). Four FLEXIT-loggings were made in each of HFR102 and HFR105, to 54 m and 198 m, respectively. The degree of repeatability serves as a quality measure. In the calculation of the final borehole deviation file, which will be “in use” displayed in Sicada (i.e. the exclusive deviation file permitted for data analyses), results from all deviation surveys are included (if not discarded for measurement technical or other quality reasons), see Section 5.4.

Results from the deviation measurements are stored in SKB’s database Sicada but are also presented in Section 5.4.

4.6 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.

4.7 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.

4.8 Nonconformities

No departures from the Activity Plan were made.

5 Results

Below, a summary of the data acquired during drilling and measurements while drilling is presented.

5.1 Overviev of the drilling of HFR101, HFR102 and HFR105

The figures 5-1 through 5-4 illustrate the logistics during drilling of HFR101, HFR102 and HFR105. Figure 5-1 provides an overview of the drilling progress for all three boreholes, whereas Figures 5-2, 5-3 and 5-4 illustrate the separate sub-activities versus time in each borehole, such as drilling, casing driving, grouting, and measurements while drilling. The horizontal axis represents real time and the vertical is the length of the borehole during the activity. The borehole water yield at different lengths is also given in the figures.

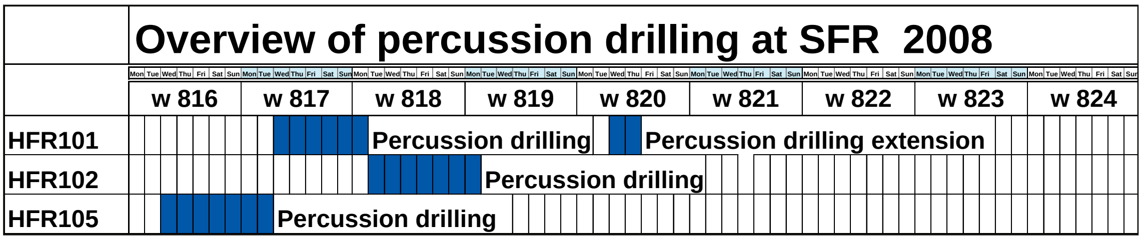


Figure 5-1. *Overview of the drilling progress for percussion boreholes HFR101, HFR102 and HFR105.*

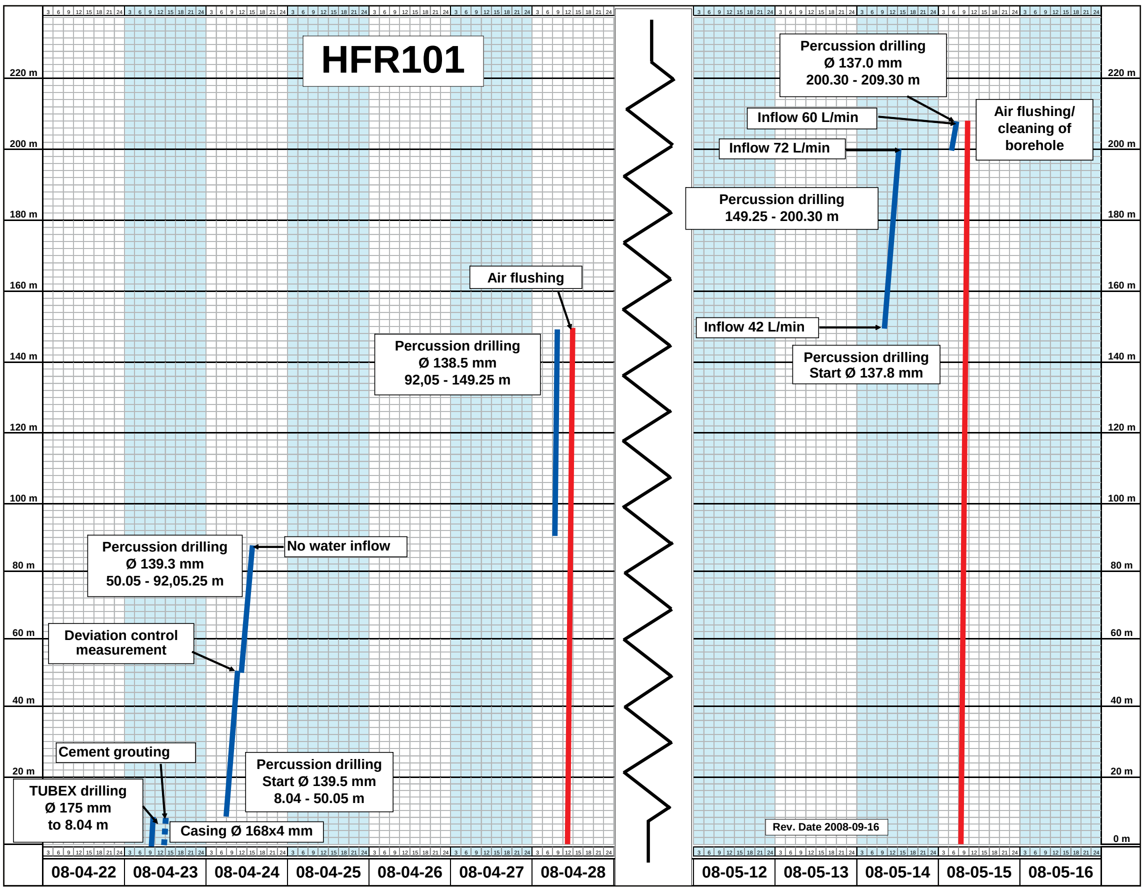


Figure 5-2. *Overview, percussion drill hole HFR101.*

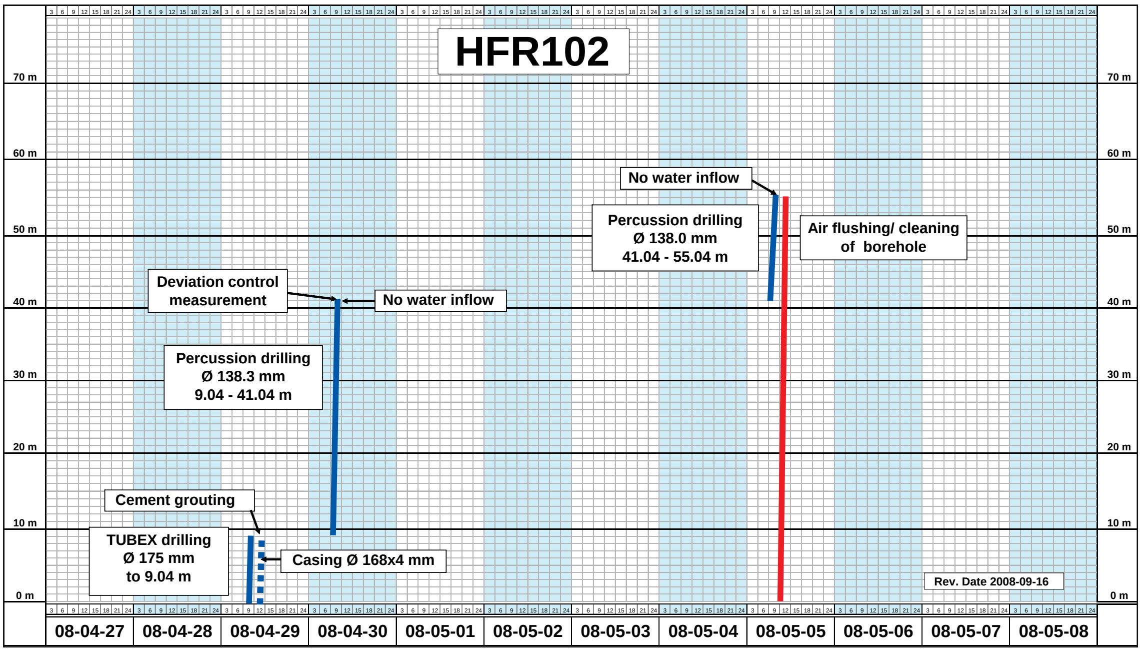


Figure 5-3. *Overview of percussion drill hole HFR102.*

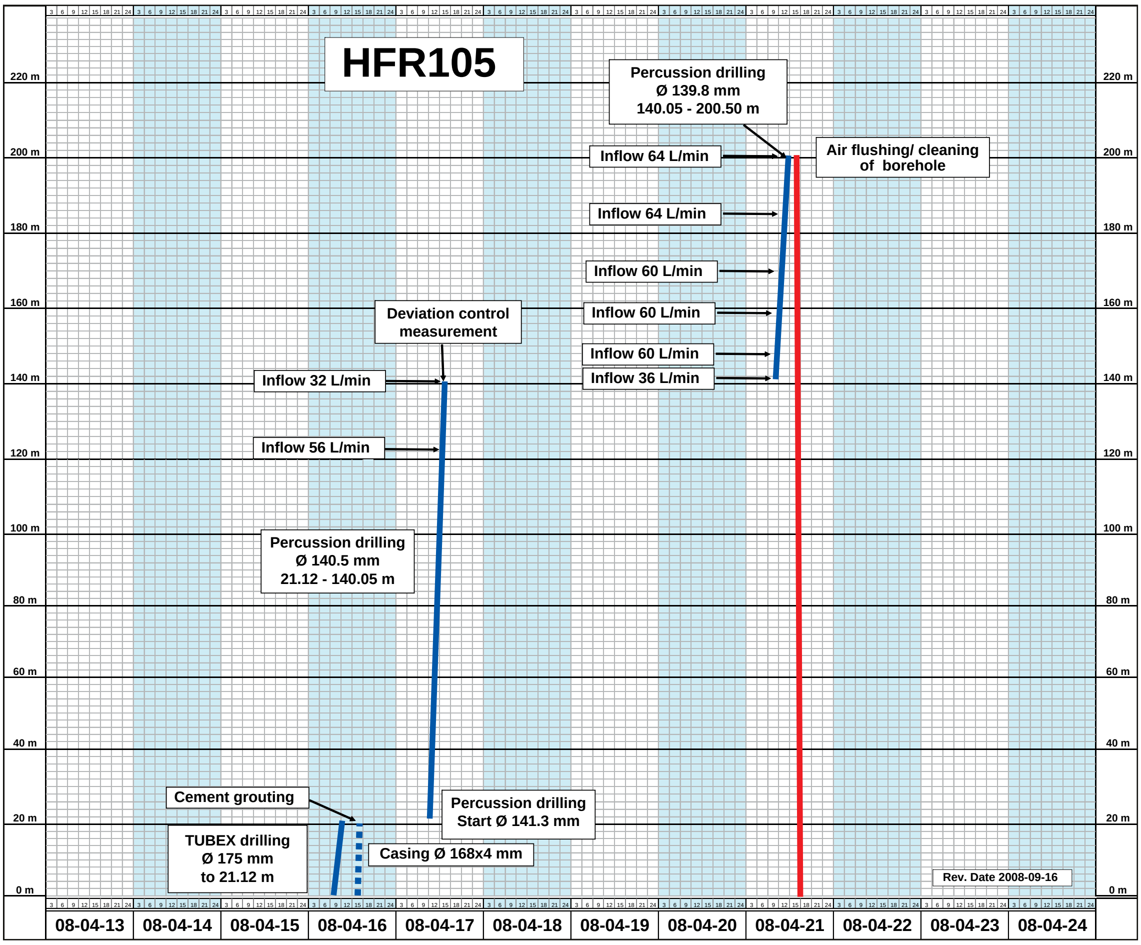


Figure 5-4. *Overview of percussion drill hole HFR105.*

5.2 Geometrical design of the percussion drilled boreholes

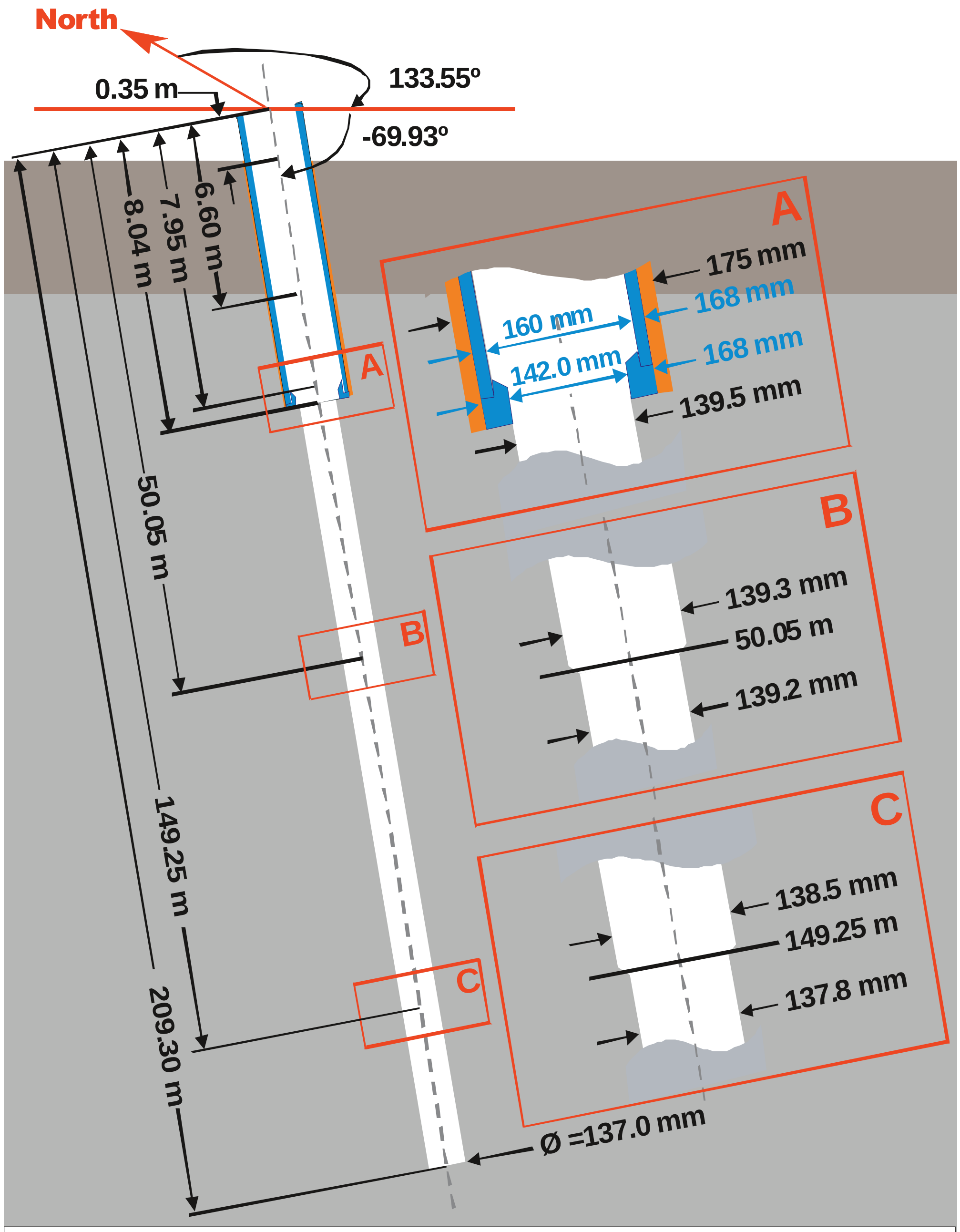
Administrative, geometric, and technical data for HFR101, HFR102 and HFR105 are presented in Table 5-1. The technical design of the boreholes is illustrated in Figures 5-5, 5-6 and 5-7. According to AP SFR-08-001 there were five percussion drill holes planned. Due to results during the drilling period of HFR101, HFR102 and HFR105 it was decided to postpone or exclude the two boreholes HFR103 and HFR104. The table below therefore does not contain data for those two holes.

Table 5-1. Administrative, geometric and technical data for boreholes HFR101, HFR102 and HFR105.

Parameter	HFR101	HFR102	HFR105
Drilling period	From 2008-04-15 to 2008-04-28	From 2008-04-29 to 2008-05-05	From 2008-04-15 to 2008-04-22
Drilling period extended borehole	From 2008-05-14 to 2008-05-15		
Borehole inclination (collaring point)	–69.93° (– = downwards)	–59.36° (– = downwards)	–61.77° (– = downwards)
Borehole bearing	133.55°	85.00°	35.43°
Borehole length	209.30 m	55.04 m	200.50 m
Borehole diameter	From 0.00 m to 8.04 m: 0.1750 m From 8.04 m to 50.05 m: decreasing from 0.1395 m to 0.1393 m From 50.05 m to 149.25 m: decreasing from 0.1392 m to 0.1385 m From 149.25 m to 209.30 m: decreasing from 0.1378 m to 0.1370 m	From 0.00 m to 9.04 m: 0.1750 m From 9.04 m to 55.04 m: decreasing from 0.1383 m to 0.1380 m	From 0.00 m to 21.12 m: 0.1750 m From 21.12 m to 140.05 m: decreasing from 0.1413 m to 0.1405 m From 140.05 m to 200.50 m: decreasing from 0.1403 m to 0.1398 m
Casing length	8.04 m	9.04 m	21.12 m
Casing diameter	$Ø_o/Ø_i$ = 168 mm/160 mm	$Ø_o/Ø_i$ = 168 mm/160 mm	$Ø_o/Ø_i$ = 168 mm/160 mm
Drill bit diameter	Start of drilling: 0.1395 m End of drilling: 0.1378 m	Start of drilling: 0.1383 m End of drilling: 0.1380 m	Start of drilling: 0.1413 m End of drilling: 0.1398 m
Collaring point coordinates (system RT90 2.5 gon V/RHB70)	Northing: 6701725.15 m Easting: 1632838.91 m Elevation: 2.63 m.a.s.l. in RBH 70	Northing: 6701728.55 m Easting: 1632974.54 m Elevation: 2.32 m.a.s.l. in RBH 70	Northing: 6701376.55 m Easting: 1632686.82 m Elevation: 3.27 m.a.s.l. in RBH 70

Technical data

Borehole HFR101



Drilling reference point

Northing:	6701725.15	(m), RT90 2,5 gon V 0:-15
Easting:	1632838.91	(m), RT90 2,5 gon V 0:-15
Elevation:	2.63	(m), RHB 70

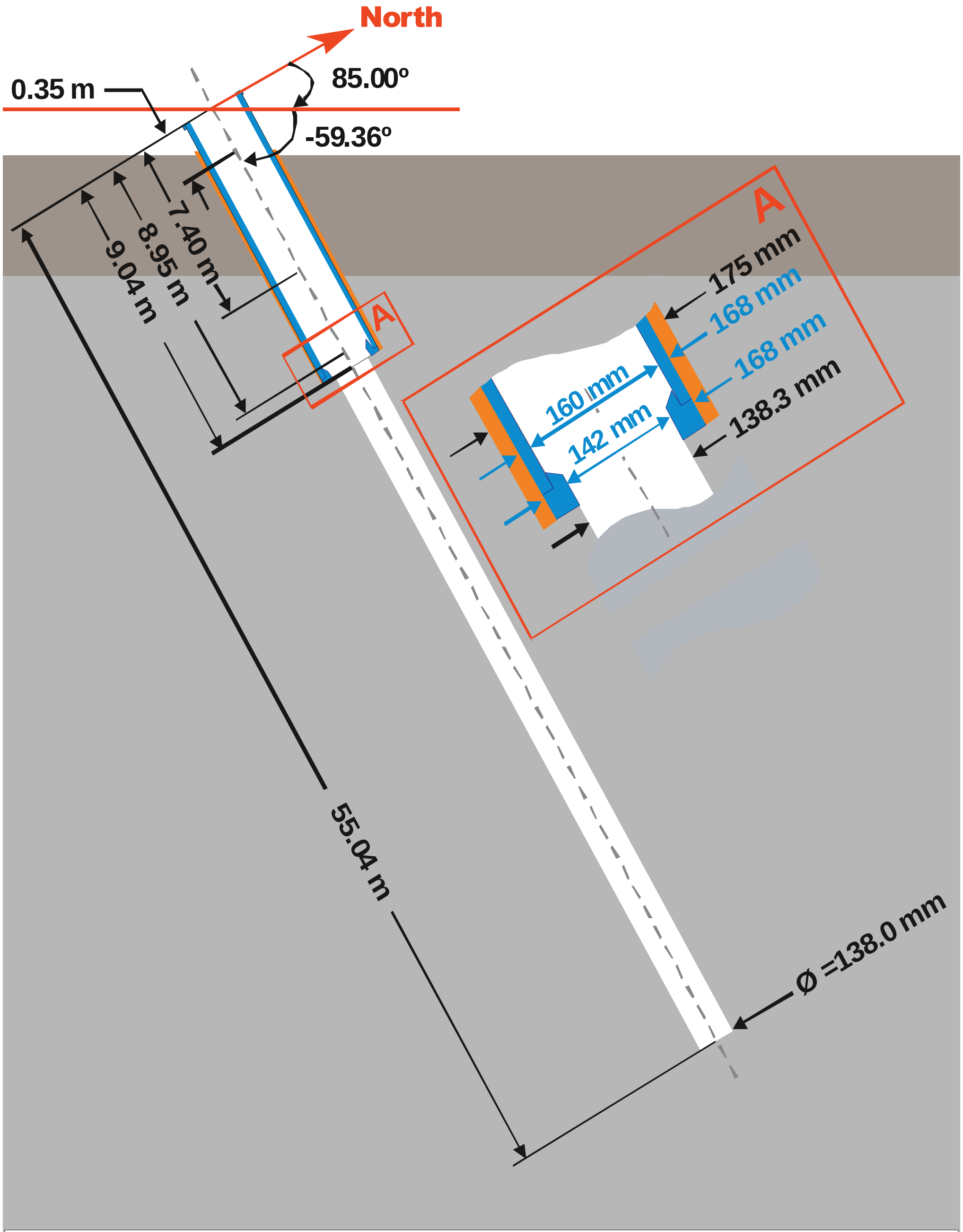
Drilling period		Borehole extended
Drilling start date:	2008-04-23	2008-05-14
Drilling stop date:	2008-04-28	2008-05-15

rev 2008-09-15

Figure 5-5. Technical data of borehole HFR101.

Technical data

Borehole HFR102



Drilling reference point

Northing:	6701728.55	(m), RT90 2,5 gon V 0:-15
Easting:	1632974.54	(m), RT90 2,5 gon V 0:-15
Elevation:	2.32	(m), RHB 70

Drilling period

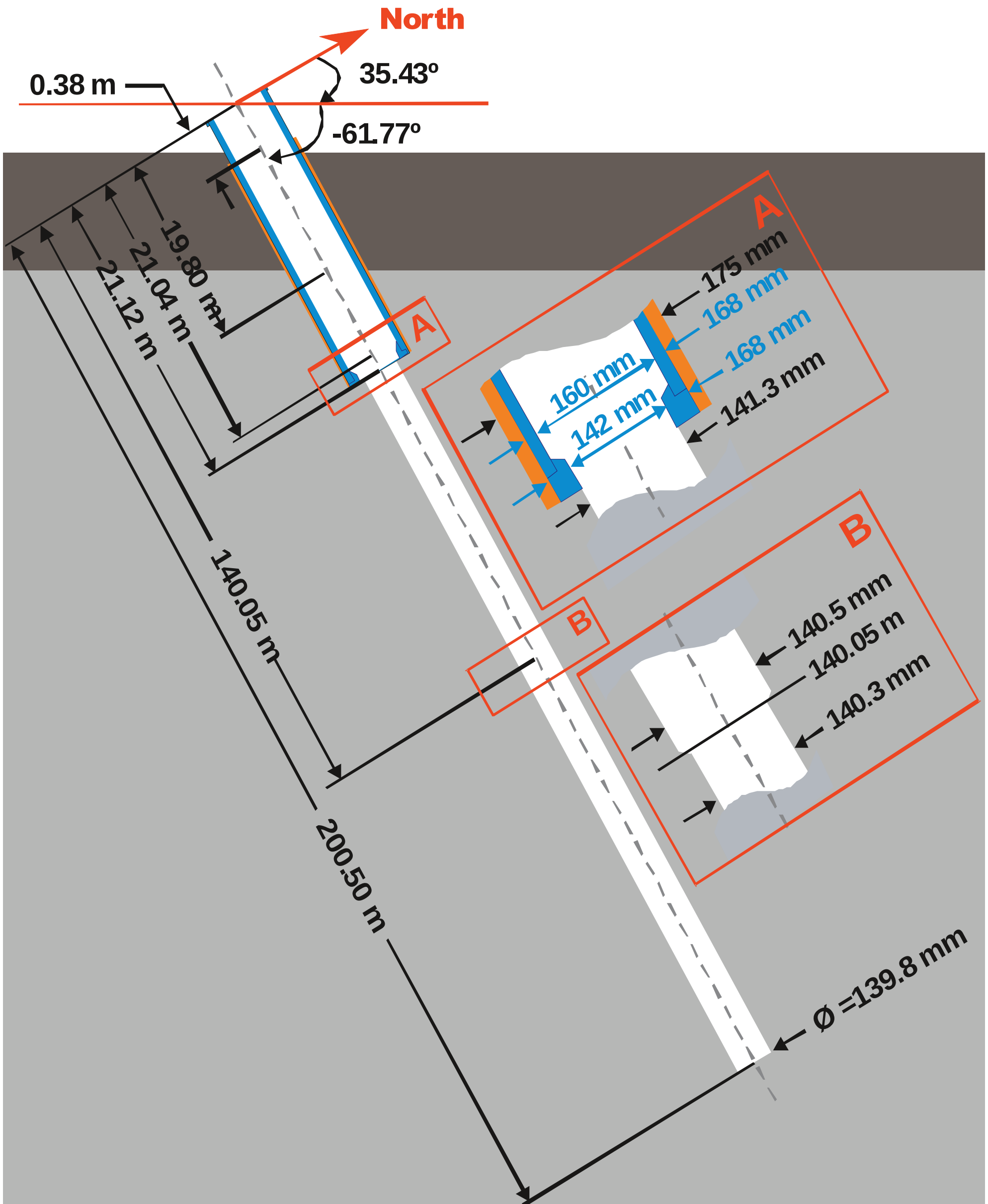
Drilling start date:	2008-04-29
Drilling stop date:	2008-05-05

rev 2 008-05-13

Figure 5-6. *Technical data of borehole HFR102.*

Technical data

Borehole HFR105



Drilling reference point

Northing:	6701376.55	(m), RT90 2,5 gon V 0:-15
Easting:	1632686.82	(m), RT90 2,5 gon V 0:-15
Elevation:	3.27	(m), RHB 70

Drilling period

Drilling start date:	2008-04-15
Drilling stop date:	2008-04-22

rev 2008-06-09

Figure 5-7. *Technical data of borehole HFR105.*

5.3 Consumables used up in HFR101, HFR102 and HFR105

The amount of oil products consumed during drilling of the boreholes HFR101, HFR102 and HFR105, and grout used for gap injection of the respective casings is reported in Tables 5-2 and 5-3, respectively. The cement was a mixed type, consisting of Standard Cement and Calcium Chloride in proportions according to Table 5-3.

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

5.4 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 variations during the deviation surveys performed (five loggings in HFR101 and four loggings in each of HFR102 and HFR105), i.e. during April 29th and May 19th 2008 (HFR101), May 6th 2008 (HFR102) and April 22nd to 23rd 2008, (HFR105), are displayed in Figures 5-8, through 5-12. Only minor disturbances are observed in the figures.

Table 5-2. Oil consumption during drilling.

Borehole ID	Hammer oil (Preem Hydra 46)	Compressor oil (Schuman 46)
HFR101	4 L	Not detectable consumption
HFR101 extension	4 L	Not detectable consumption
HFR102	3 L	Not detectable consumption
HFR105	6 L	Not detectable consumption

Table 5-3. Consumption of cement grouting.

Borehole ID	Casing length		Cement weight (Standard cement /Calcium chloride)	Grouting method (See under 3.2 for methode description)
	From	To		
HFR101	7.5 m	8.0 m	20 kg/0.4 kg	Cement balls
HFR102	8.5 m	9.0 m	20 kg/0.4 kg	Cement balls
HFR105	20.4 m	21.12 m	20 kg/0.0 kg	Cement balls

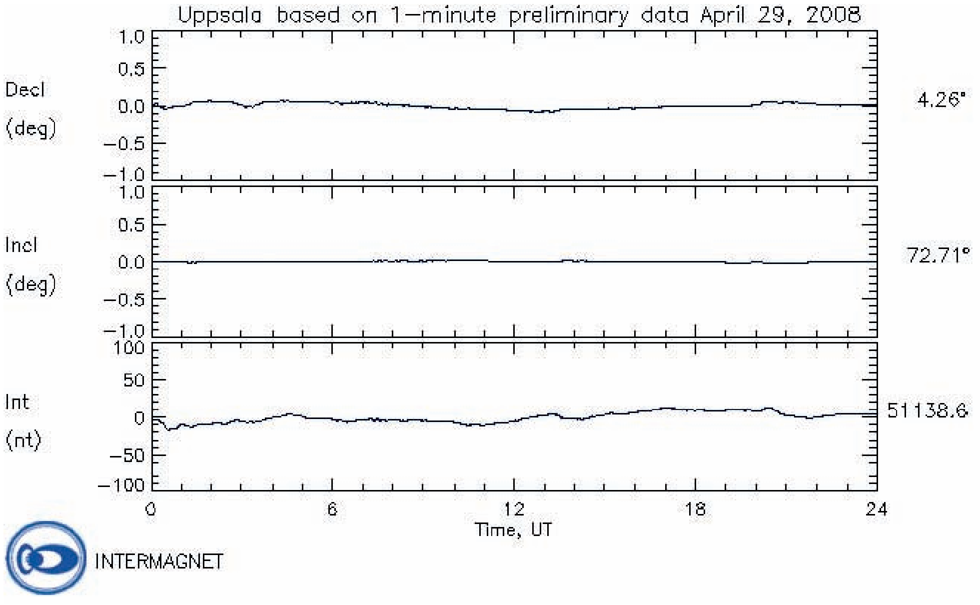


Figure 5-8. *Magnetic field variation during FLEXIT surveys performed April 29th 2008 in HFR101.*

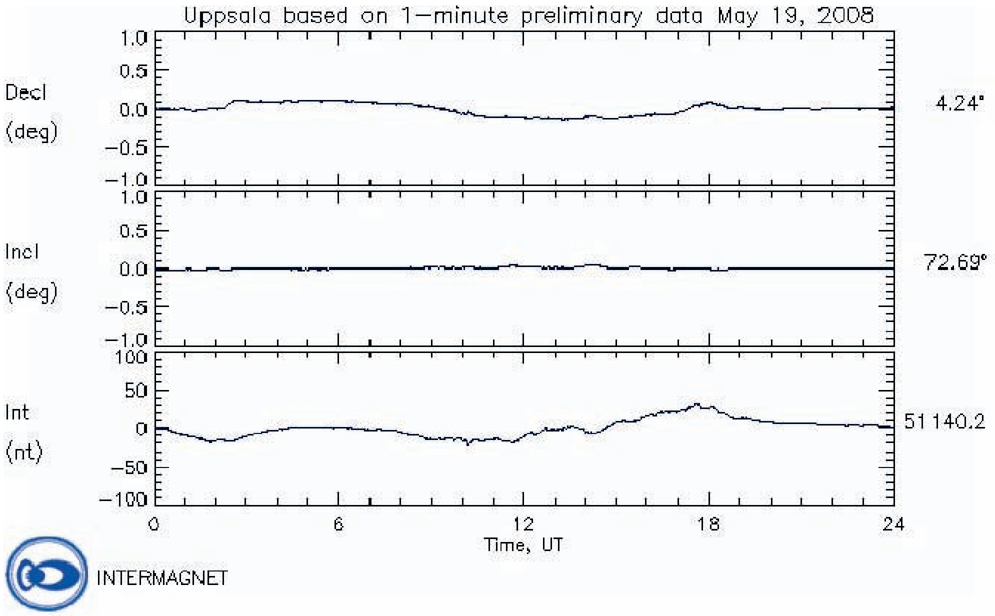


Figure 5-9. *Magnetic field variation during FLEXIT surveys performed May 19th 2008 in HFR101.*

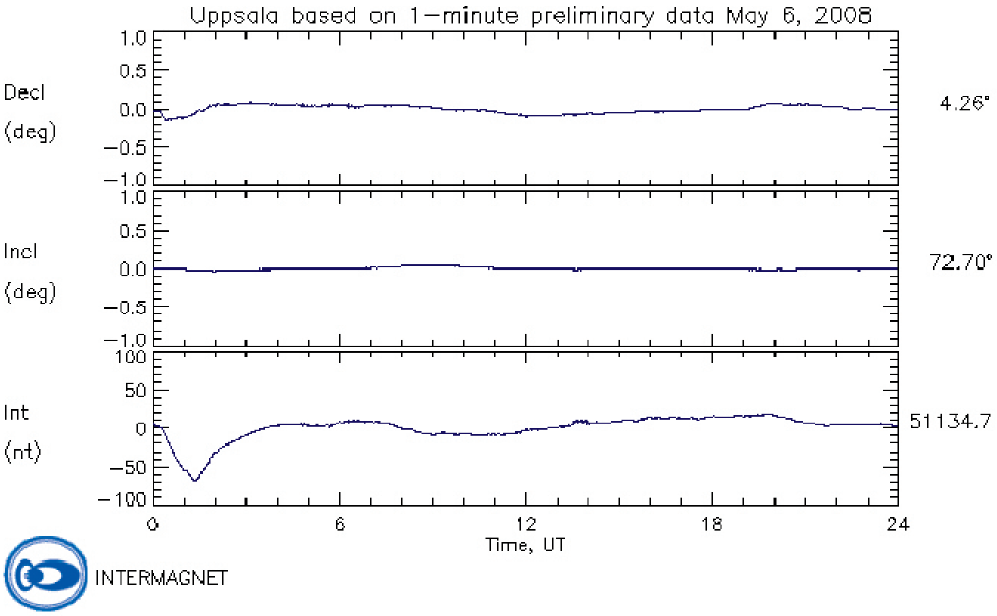


Figure 5-10. *Magnetic field variation during FLEXIT surveys performed May 6th 2008 in HFR102.*

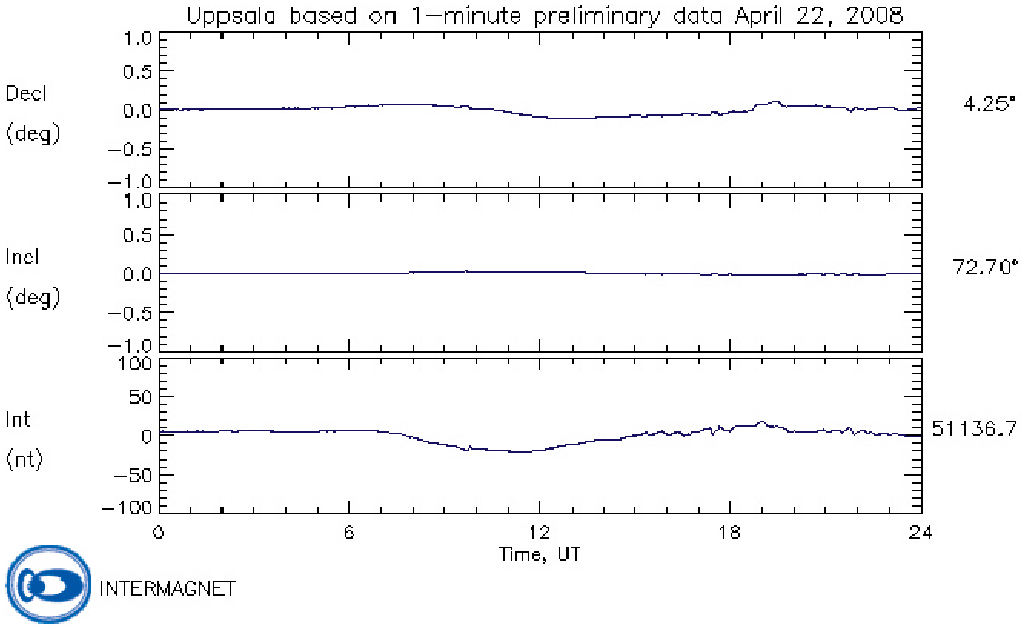


Figure 5-11. *Magnetic field variation during FLEXIT surveys performed April 22nd 2008 in HFR105.*

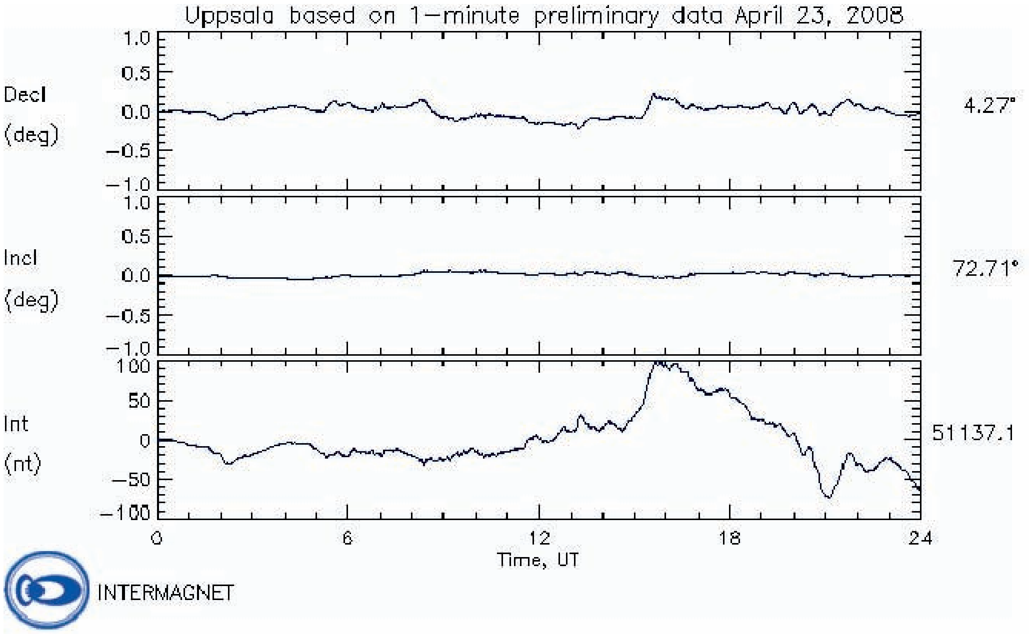


Figure 5-12. *Magnetic field variation during FLEXIT surveys performed April 23rd 2008 in HFR105.*

In the following a description of the construction of deviation data for the percussion drilled boreholes HFR101, HFR102 and HFR105 is given.

The principles of the equipment for and performance of deviation measurements were explained in Sections 3.3 and 4.5, respectively.

The deviation data used are for construction of the final deviation files are one FLEXIT-logging to 147 m borehole length and four loggings to 207 m borehole length in HFR101, four loggings to 54 m borehole length in HFR102 and four loggings to 198 m borehole length in HFR105, respectively, see Table 5-4. With the FLEXIT Smart Tool System, the deviation measurements in all three boreholes were carried out every 3 m both downwards and upwards. The used activity marked "CF" also includes comments as well as a file describing the measures that have been applied.

All magnetic accelerometer surveys in each borehole have followed the recommended quality routines according to SKB MD 224.001, Version 4.0, and were therefore chosen for the construction of the deviation file to be "in use" displayed in Sicada (see explanation in Section 4.5.). This file is termed EG154 (Borehole deviation multiple measurements). See illustration of the construction principle in Figure 5-13.

The EG154-activity specifies the sections of the deviation measurements used in the resulting calculation presented in Table 5-5. The different length of the upper sections between the bearing and the inclination are chosen due to that the magnetic accelerometer measurement (bearing) is influenced by the 9 and 21 m steel casing which is not the case for the inclinometer measurements (inclination).

Table 5-4. Activity data for deviation measurements approved for HFR101, HFR102 and HFR105 (from Sicada).

Idcode	Activity ID	Activity Type code	Activity	Start date	Secup	Seclow	Flags
HFR101	13187410	EG157	Magnetic – accelerometer measurement	2008-04-29 13:00	3.00	147.00	CF
HFR101	13187411	EG157	Magnetic – accelerometer measurement	2008-05-19 13:27	3.00	207.00	CF
HFR101	13187413	EG157	Magnetic – accelerometer measurement	2008-05-19 14:17	3.00	207.00	CF
HFR101	13187412	EG157	Magnetic – accelerometer measurement	2008-05-19 14:52	3.00	207.00	CF
HFR101	13187414	EG157	Magnetic – accelerometer measurement	2008-05-19 15:26	3.00	207.00	CF
HFR101	13187775	EG154	Borehole deviation multiple measurements	2008-05-21 09:00			I C
HFR102	13186212	EG157	Magnetic – accelerometer measurement	2008-05-06 09:30	3.00	54.00	CF
HFR102	13186330	EG157	Magnetic – accelerometer measurement	2008-05-06 09:41	3.00	54.00	CF
HFR102	13186320	EG157	Magnetic – accelerometer measurement	2008-05-06 10:11	3.00	54.00	CF
HFR102	13186331	EG157	Magnetic – accelerometer measurement	2008-05-06 10:22	3.00	54.00	CF
HFR102	13186502	EG154	Borehole deviation multiple measurements	2008-05-15 15:20			I C
HFR105	13186172	EG157	Magnetic – accelerometer measurement	2008-04-22 16:06	3.00	198.00	CF
HFR105	13186176	EG157	Magnetic – accelerometer measurement	2008-04-22 16:47	3.00	198.00	CF
HFR105	13186171	EG157	Magnetic – accelerometer measurement	2008-04-23 07:40	3.00	198.00	CF
HFR105	13186177	EG157	Magnetic – accelerometer measurement	2008-04-23 08:16	3.00	198.00	CF
HFR105	13186336	EG154	Borehole deviation multiple measurements	2008-05-15 12:30			I C

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

ID code	Deviation Activity ID	Deviation Angle type	Approved Secup (m)	Approved Seclow (m)	Mean estim. angle Uncert. (± degrees)
HFR101	13186171	Bearing	24.00	198.00	0.356
HFR101	13186171	Inclination	3.00	198.00	0.160
HFR101	13186172	Bearing	24.00	198.00	0.356
HFR101	13186172	Inclination	3.00	198.00	0.160
HFR101	13186176	Bearing	24.00	198.00	0.356
HFR101	13186176	Inclination	3.00	198.00	0.160
HFR101	13186177	Bearing	24.00	198.00	0.356
HFR101	13186177	Inclination	3.00	198.00	0.160
HFR102	13186212	Bearing	12.00	54.00	0.175
HFR102	13186212	Inclination	3.00	54.00	0.094
HFR102	13186320	Bearing	12.00	54.00	0.175
HFR102	13186320	Inclination	3.00	54.00	0.094
HFR102	13186330	Bearing	12.00	54.00	0.175
HFR102	13186330	Inclination	3.00	54.00	0.094
HFR102	13186331	Bearing	12.00	54.00	0.175
HFR102	13186331	Inclination	3.00	54.00	0.094
HFR105	13187410	Bearing	12.00	147.00	0.420
HFR105	13187410	Inclination	3.00	147.00	0.070
HFR105	13187411	Bearing	12.00	204.00	0.420
HFR105	13187411	Inclination	3.00	207.00	0.070
HFR105	13187412	Bearing	12.00	207.00	0.420
HFR105	13187412	Inclination	3.00	207.00	0.070
HFR105	13187413	Bearing	12.00	207.00	0.420
HFR105	13187413	Inclination	3.00	207.00	0.070
HFR105	13187414	Bearing	12.00	207.00	0.420
HFR105	13187414	Inclination	3.00	207.00	0.070

A subset of the resulting deviation files and the estimated radius uncertainty is presented in Tables 5-6, 5-7 and 5-8. Figure 5-13 illustrates the principles behind computing the borehole deviation, i.e. the borehole geometry, from several measurements, and also displays the concept of radial uncertainty.

The calculated deviation (EG154-file) in borehole HFR101 shows that the borehole deviates upwards with an absolute deviation of 18.1 m compared to an imagined straight line following the dip and strike of the borehole start point. However, the borehole is almost straight in the horizontal plane.

The calculated deviation (EG154-file) in borehole HFR102 indicates that the borehole deviates upwards and to the right with an absolute deviation of 2.1 m compared to an imagined straight line following the dip and strike of the borehole start point.

The calculated deviation (EG154-file) in borehole HFR105 illustrates that the borehole deviates downwards with an absolute deviation of 10.4 m compared to an imagined straight line following the dip and strike of the borehole start point. The borehole is though almost straight in the horizontal direction.

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.

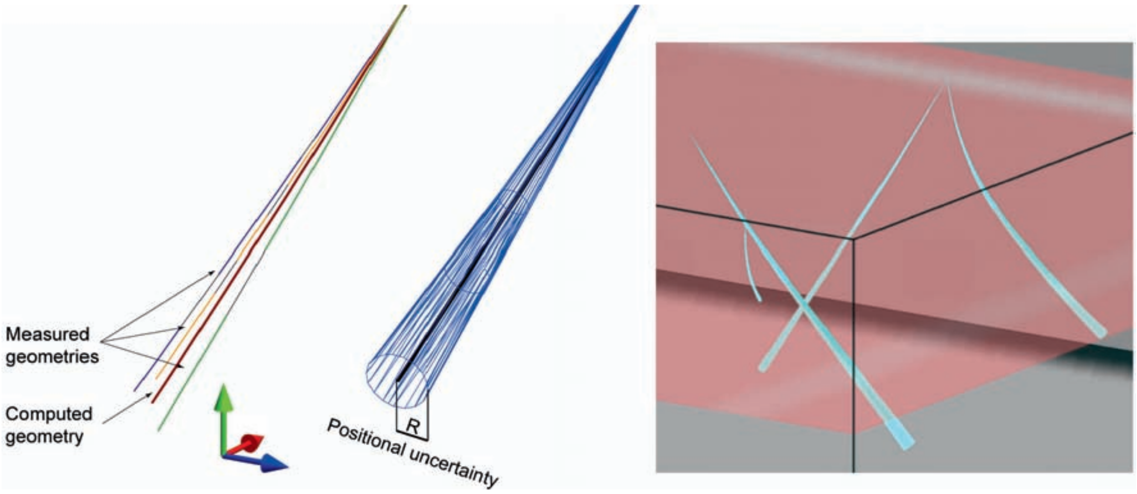


Figure 5-13. *The figure to the left is an illustration of the principles for calculating the borehole geometry from several deviation measurements. The two other figures illustrate one of the uncertainty measures used for deviation measurements. In the middle figure, "R" denotes "Radial uncertainty", representing a function, which is monotonously increasing versus borehole length in relation to the borehole axis, defining the shape of a cone surrounding the borehole axis and corresponding to the parameter in the column furthest to the right in Tables 5-6, 5-7 and 5-8. The figure to the right is a block diagram imaging four fictitious boreholes deviating in different ways and with radius uncertainty illustrated as blue cones (modified after Figures 4-1, 5-1 and 5-3 in /4/.*

Table 5-6. Deviation and uncertainty data for the deviation measurements in HFR101 for approximately every 10 m vertical length calculated from EG154.

Idcode	Northing (m)	Easting (m)	Elev. (m)	Length (m)	Vertical depth (m)	Inclin. (degrees)	Bearing (degrees)	Inclin. uncert. (degrees)	Bearing uncert. (degrees)	Radius uncert. (m)
HFR101	6701725.15	1632838.91	2.63	0	0	–70.04*	133.55	0.16	0.36	0.00
HFR101	6701722.33	1632841.86	–8.65	12	11.29	–70.13	133.94	0.16	0.36	0.03
HFR101	6701719.44	1632844.83	–19.91	24	22.55	–69.31	134.45	0.16	0.36	0.07
HFR101	6701716.42	1632847.90	–31.11	36	33.75	–68.68	134.87	0.16	0.36	0.10
HFR101	6701713.26	1632851.02	–42.26	48	44.89	–68	135.78	0.16	0.36	0.13
HFR101	6701709.99	1632854.19	–53.36	60	56.00	–67.43	136.26	0.16	0.36	0.17
HFR101	6701706.61	1632857.41	–64.42	72	67.05	–66.72	136.73	0.16	0.36	0.20
HFR101	6701703.09	1632860.69	–75.41	84	78.05	–66.04	137.09	0.16	0.36	0.24
HFR101	6701699.49	1632864.05	–86.35	96	88.99	–65.38	137.15	0.16	0.36	0.27
HFR101	6701695.78	1632867.47	–97.24	108	99.88	–64.89	137.63	0.16	0.36	0.30
HFR101	6701691.97	1632870.95	–108.08	120	110.71	–64.18	137.38	0.16	0.36	0.34
HFR101	6701688.08	1632874.53	–118.85	132	121.48	–63.55	137.08	0.16	0.36	0.37
HFR101	6701684.13	1632878.23	–129.56	144	132.19	–62.93	136.75	0.16	0.36	0.40
HFR101	6701680.12	1632882.02	–140.22	156	142.85	–62.3	136.40	0.16	0.36	0.44
HFR101	6701676.07	1632885.94	–150.81	168	153.44	–61.64	135.71	0.16	0.36	0.47
HFR101	6701671.97	1632889.98	–161.34	180	163.97	–61.03	135.14	0.16	0.36	0.51
HFR101	6701667.85	1632894.14	–171.81	192	174.45	–60.61	134.46	0.16	0.36	0.54
HFR101	6701663.71	1632898.37	–182.25	204	184.88	–60.22	134.37	0.16	0.36	0.58
HFR101	6701661.87	1632900.26	–186.85	209.3	189.48	–60.17	134.18	0.16	0.36	0.60

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

Table 5-7. Deviation and uncertainty data for the deviation measurements in HFR102 for approximately every 6 m vertical length calculated from EG154.

Idcode	Northing (m)	Easting (m)	Elev. (m)	Length (m)	Vertical depth (m)	Inclin. (degrees)	Bearing (degrees)	Inclin. uncert. (degrees)	Bearing uncert. (degrees)	Radius uncert. (m)
HFR102	6701728.55	1632974.54	2.32	0	0.00	–59.14*	85.00	0.094	0.175	0
HFR102	6701728.81	1632977.63	–2.82	6	5.14	–58.49	85.92	0.094	0.175	0.01
HFR102	6701728.99	1632980.80	–7.91	12	10.23	–57.84	86.92	0.094	0.175	0.02
HFR102	6701729.17	1632983.99	–12.99	18	15.31	–57.81	86.92	0.094	0.175	0.03
HFR102	6701729.34	1632987.18	–18.06	24	20.38	–57.66	87.02	0.094	0.175	0.04
HFR102	6701729.50	1632990.39	–23.13	30	25.45	–57.47	87.28	0.094	0.175	0.049
HFR102	6701729.65	1632993.62	–28.18	36	30.50	–57.26	87.48	0.094	0.175	0.059
HFR102	6701729.79	1632996.88	–33.22	42	35.54	–56.91	87.60	0.094	0.175	0.069
HFR102	6701729.92	1633000.17	–38.24	48	40.55	–56.45	87.82	0.094	0.175	0.08
HFR102	6701730.05	1633003.51	–43.22	54	45.54	–56.10	87.88	0.094	0.175	0.09
HFR102	6701730.07	1633004.09	–44.09	55.04	46.40	–56.10	87.88	0.094	0.175	0.092

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

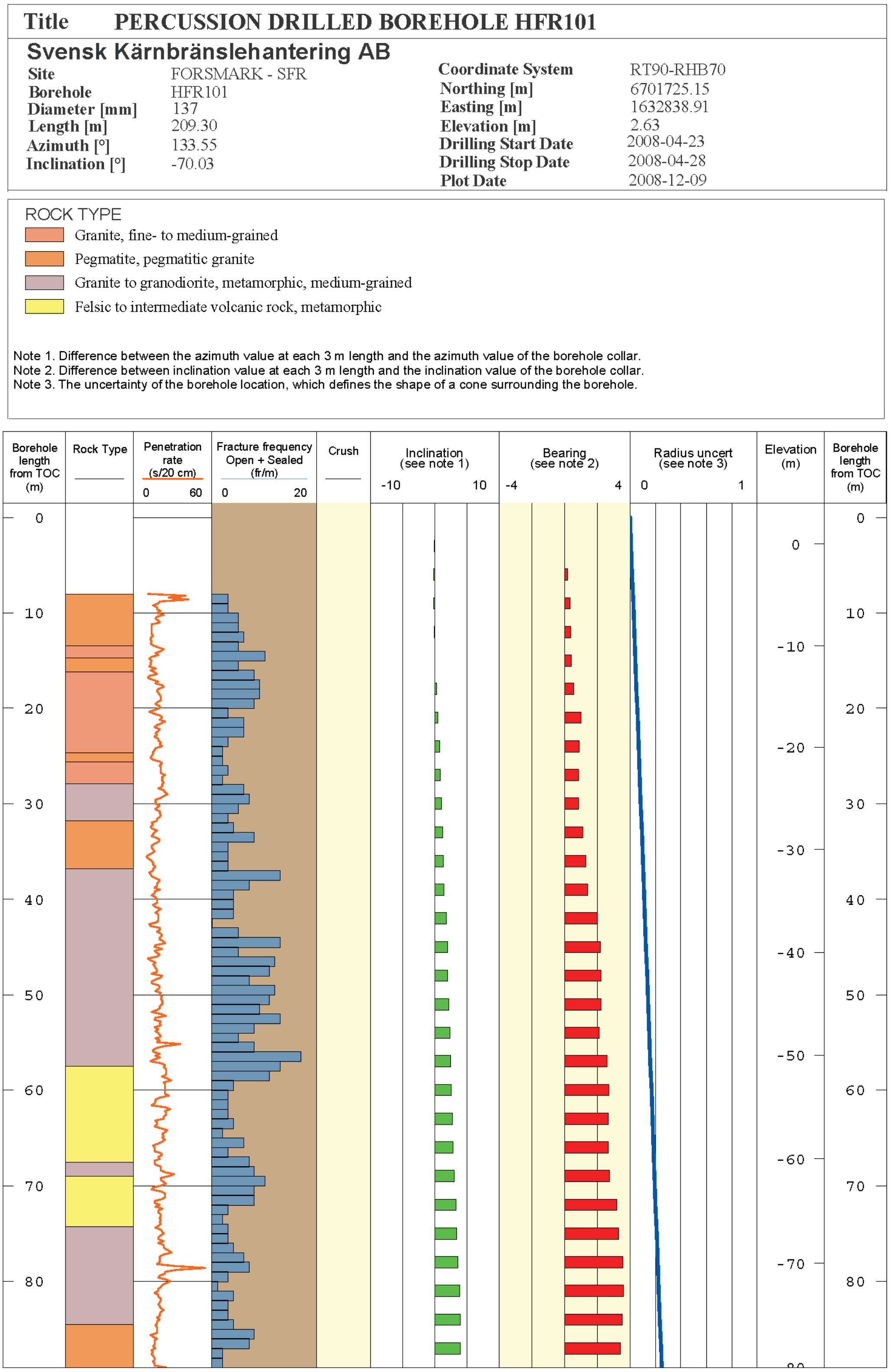
Table 5-8. Deviation data and uncertainty data for the deviation measurements in HFR102 for approximately every 10 m vertical length calculated from EG154.

Idcode	Northing (m)	Easting (m)	Elev. (m)	Length (m)	Vertical depth (m)	Inclin. (degrees)	Bearing (degrees)	Inclin. uncert. (degrees)	Bearing uncert. (degrees)	Radius uncert. (m)
HFR105	6701376.55	1632686.82	3.27	0.0	0.00	–61.91*	35.43	0.07	0.42	0
HFR105	6701381.10	1632689.99	–7.37	12.0	10.64	–63.10	34.10	0.07	0.42	0.04
HFR105	6701385.63	1632692.97	–18.07	24.0	21.34	–63.12	32.78	0.07	0.42	0.08
HFR105	6701390.19	1632695.92	–28.78	36.0	32.05	–63.12	33.02	0.07	0.42	0.12
HFR105	6701394.67	1632698.89	–39.51	48.0	42.78	–63.55	33.94	0.07	0.42	0.16
HFR105	6701399.07	1632701.86	–50.27	60.0	53.54	–63.92	34.28	0.07	0.42	0.20
HFR105	6701403.38	1632704.81	–61.07	72.0	64.34	–64.54	34.57	0.07	0.42	0.24
HFR105	6701407.54	1632707.70	–71.95	84.0	75.22	–65.41	34.87	0.07	0.42	0.27
HFR105	6701411.66	1632710.54	–82.86	96.0	86.13	–65.44	34.27	0.07	0.42	0.31
HFR105	6701415.76	1632713.30	–93.79	108.0	97.06	–65.78	33.68	0.07	0.42	0.35
HFR105	6701419.88	1632716.00	–104.73	120.0	108.00	–65.69	33.10	0.07	0.42	0.38
HFR105	6701423.98	1632718.74	–115.67	132.0	118.94	–65.75	34.39	0.07	0.42	0.42
HFR105	6701428.01	1632721.57	–126.62	144.0	129.89	–65.80	35.60	0.07	0.42	0.46
HFR105	6701432.08	1632724.46	–137.53	156.0	140.80	–65.37	35.20	0.07	0.42	0.49
HFR105	6701436.16	1632727.33	–148.44	168.0	151.71	–65.49	35.59	0.07	0.42	0.53
HFR105	6701440.21	1632730.24	–159.36	180.0	162.63	–65.35	35.67	0.07	0.42	0.56
HFR105	6701444.28	1632733.17	–170.26	192.0	173.53	–65.29	35.67	0.07	0.42	0.60
HFR105	6701446.33	1632734.64	–175.71	198.0	178.98	–65.19	35.67	0.07	0.42	0.62
HFR105	6701447.18	1632735.25	–177.97	200.5	181.25	–65.19	35.67	0.07	0.42	0.63

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

5.5 Well Cad presentations

Geoscientific results achieved during drilling are presented in the so called Well Cad plots in Figure 5-14, Figure 5-15 and Figure 5-16.



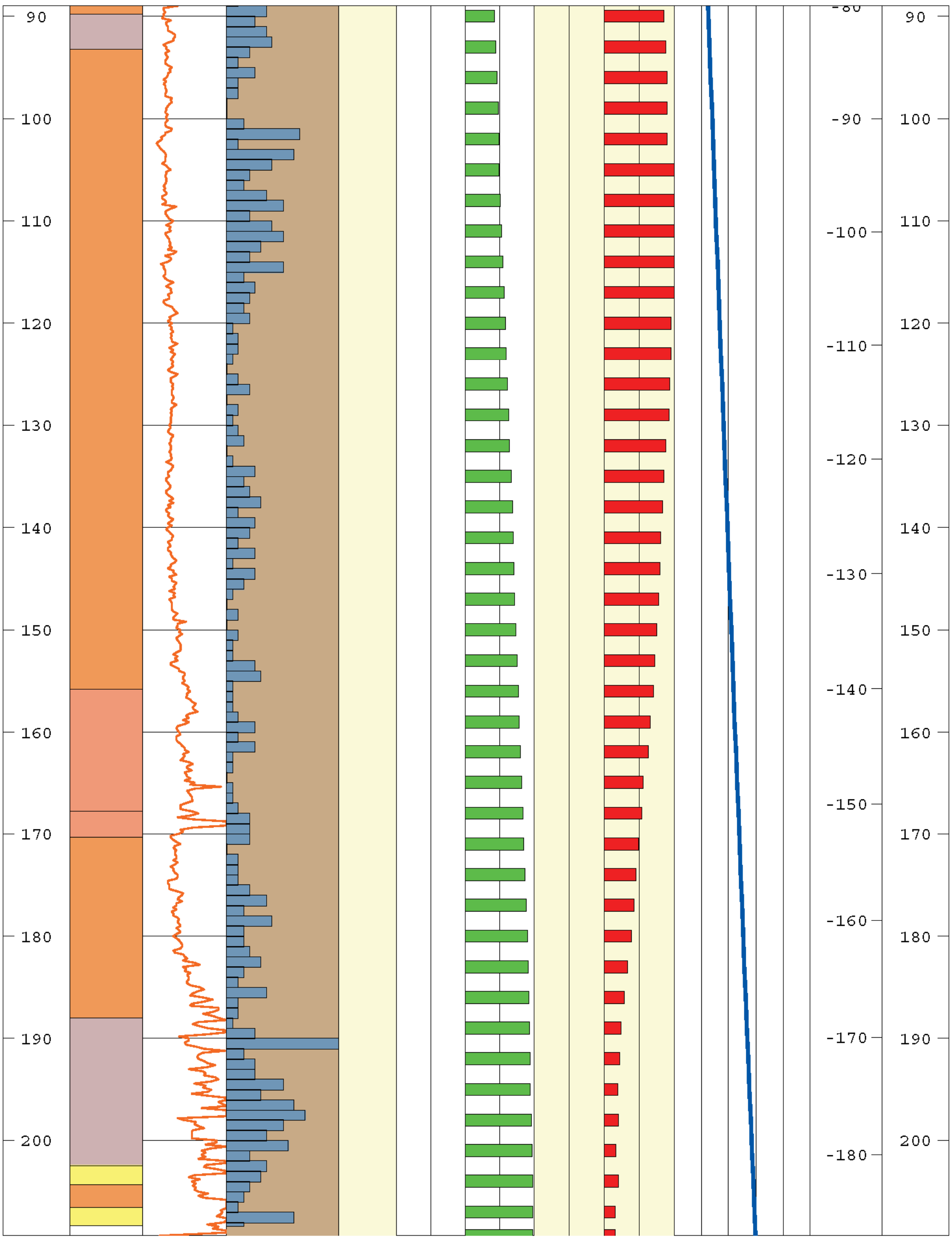


***Figure 5-14.** Geoscientific data acquired during drilling of borehole HFR101.*

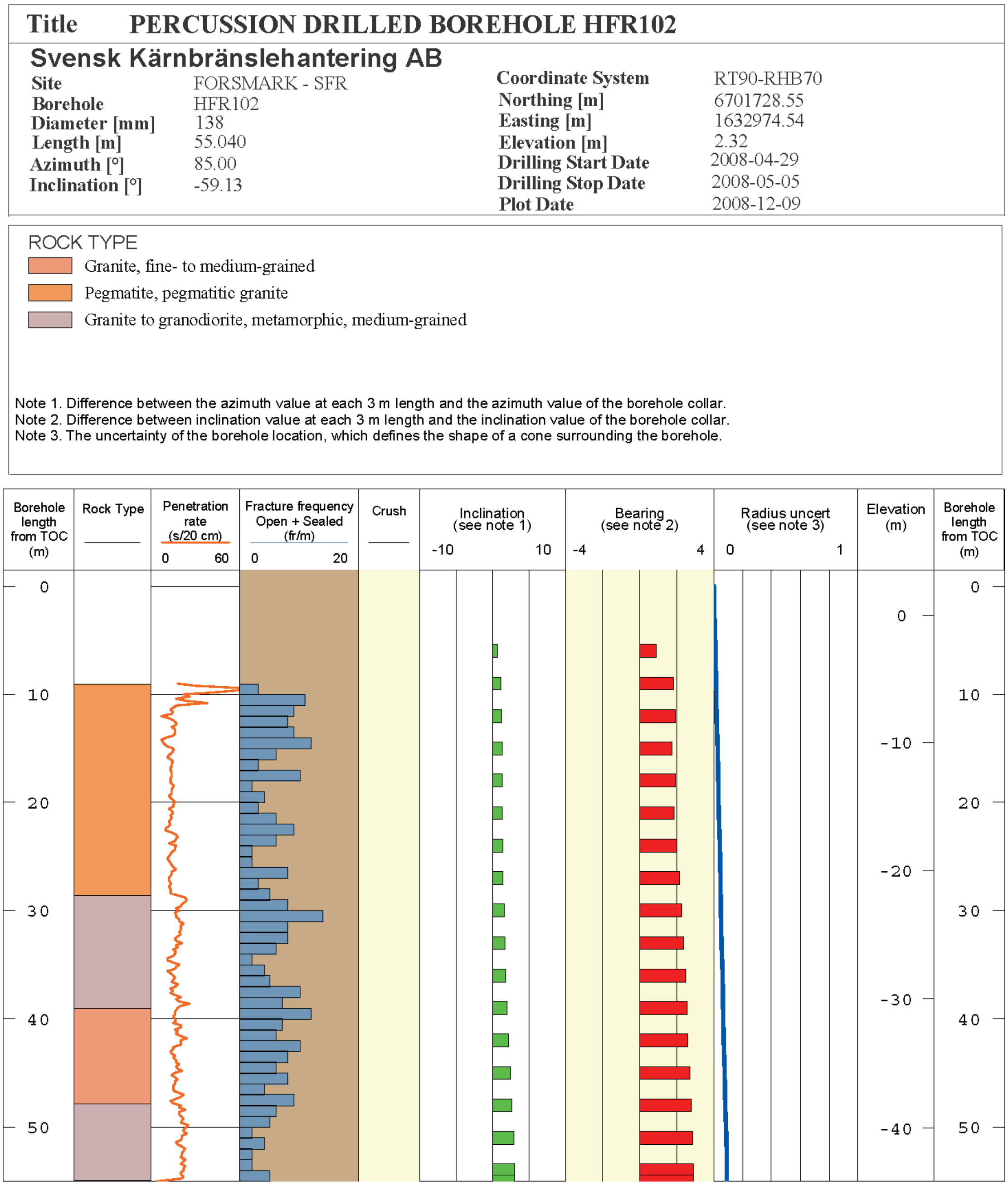


***Figure 5-15.** Geoscientific data acquired during drilling of borehole HFR102.*

Title **PERCUSSION DRILLED BOREHOLE HFR105**

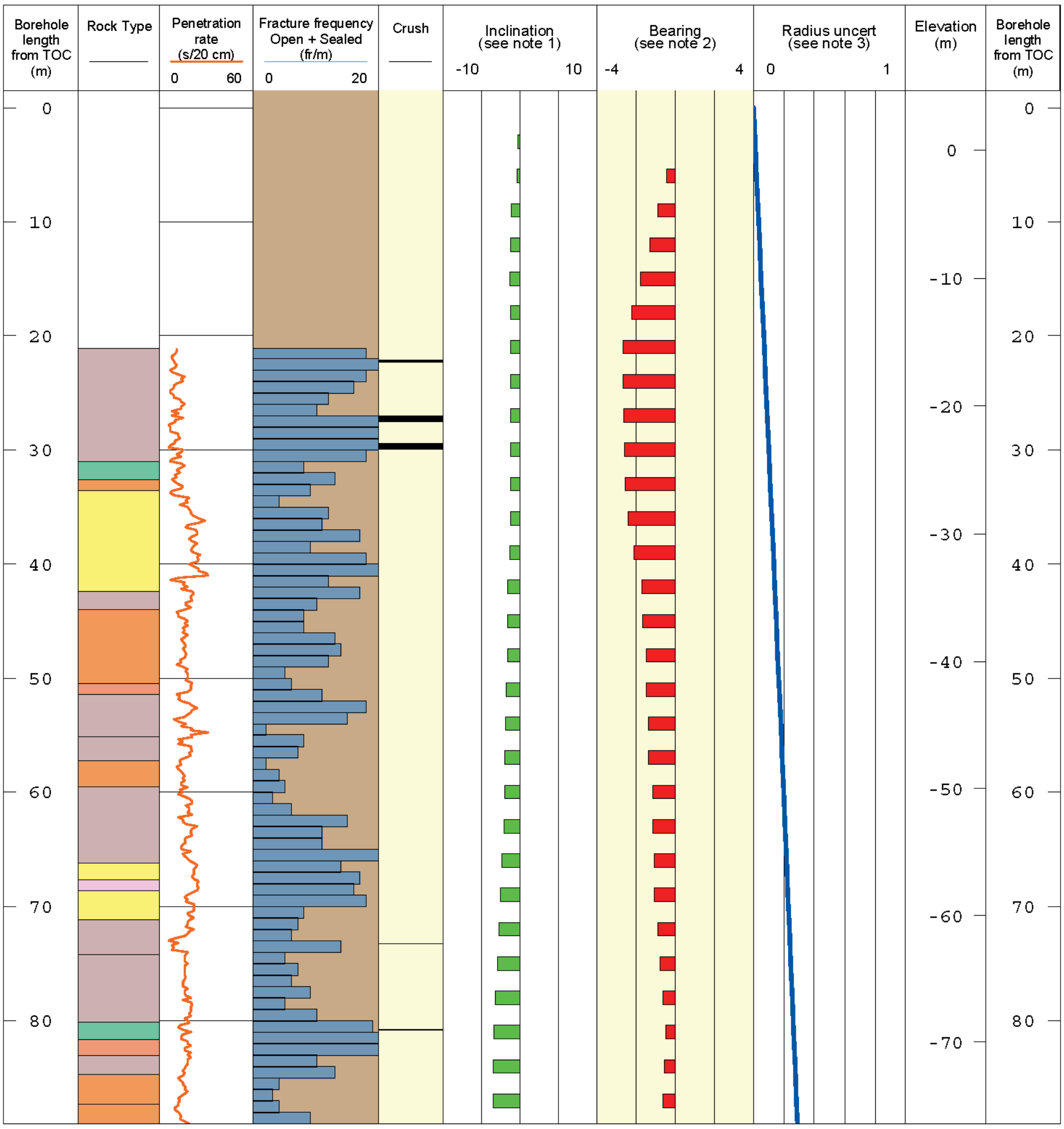
Svensk Kärnbränslehantering AB

Site	FORSMARK - SFR	**Coordinate System**	RT90-RHB70
Borehole	HFR105	**Northing [m]**	6701376.55
Diameter [mm]	140	**Easting [m]**	1632686.82
Length [m]	200.50	**Elevation [m]**	3.27
Azimuth [°]	35.43	**Drilling Start Date**	2008-04-16
Inclination [°]	-61.90	**Drilling Stop Date**	2008-04-22
		Plot Date	2008-12-09

ROCK TYPE

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

Note 1. Difference between the azimuth value at each 3 m length and the azimuth value of the borehole collar.
Note 2. Difference between inclination value at each 3 m length and the inclination value of the borehole collar.
Note 3. The uncertainty of the borehole location, which defines the shape of a cone surrounding the borehole.



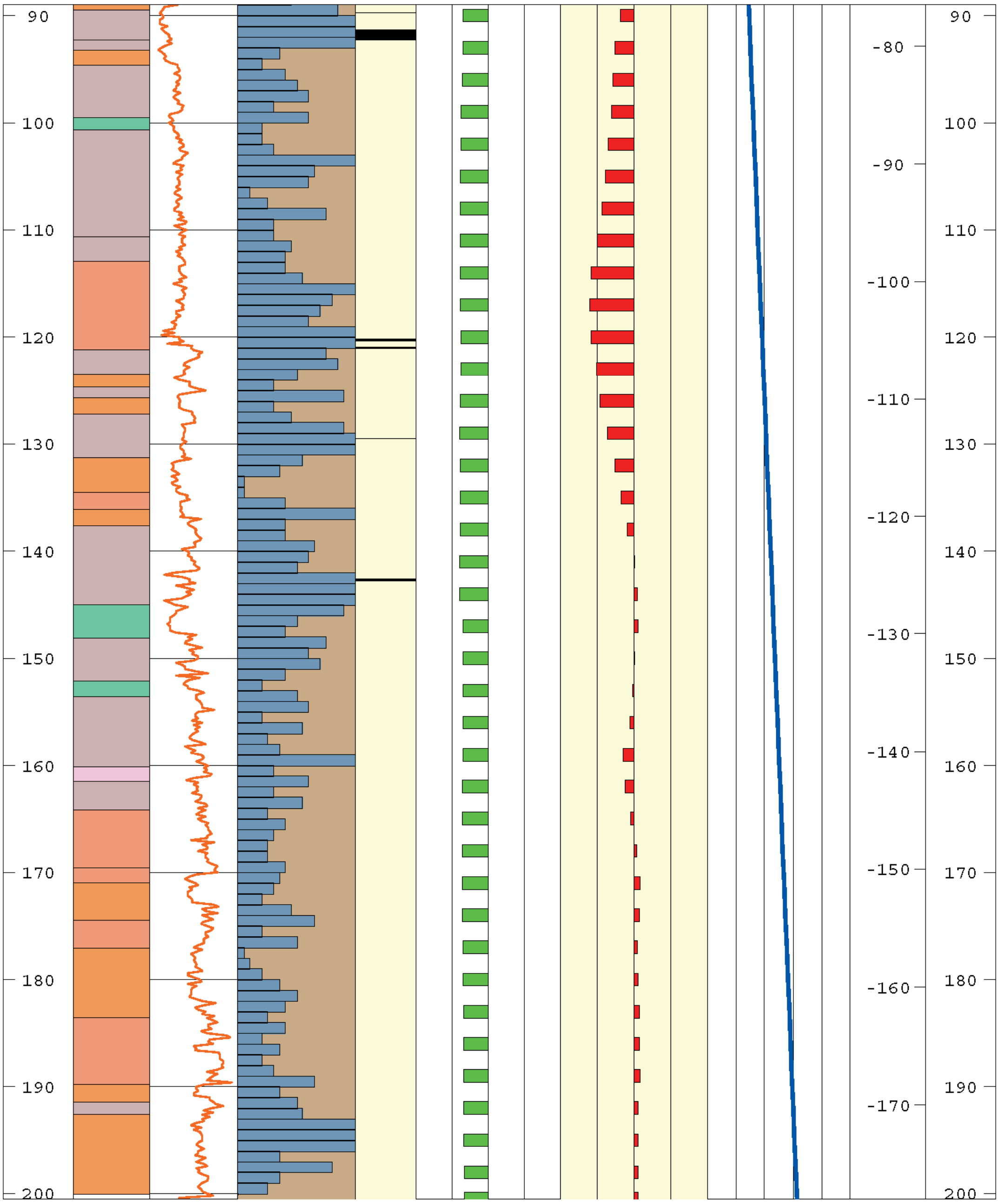


Figure 5-16. *Geoscientific data acquired during drilling of borehole HFR105.*

5.6 Hydrogeology

5.6.1 Observations during drilling

The site investigations for a deep repository at Forsmark have revealed gently dipping, often highly water-yielding structures down to a couple of hundred metres from the rock surface, especially within the so called Forsmark tectonic lens, see for example /5/, The percussion-drilled boreholes HFR101, HFR102 and HFR105, located c. 3 km W of the tectonic lens, do not seem to fit into this pattern.

During drilling of and sampling in borehole HFR101, no water inflow was observed to 149.25 m. A decision was made to extend the borehole, and three weeks after drilling was completed at 149.25 m an accumulated inflow of 40 L/min was observed when the borehole was flushed (before drilling restarted). Below 149.25 a minor water yield was observed but only as damp in the recovered drilling debris. However, when drilling continued, the inflow successively increased, fluctuating between 40–70 L/min and ending at 60 L/min, see Figure 5-17. The electrical conductivity of the groundwater (EC-value) kept stable around 1,100 mS/m during extension of the borehole from 149.25 m to 209.30 m.

In HFR105, an inflow of 56 L/min was encountered at 121 m drilling length. The electrical conductivity of the groundwater (EC-value) amounted initially to 600 mS/m (see Figure 5-18). This low value was probably an effect of that tap water was added to the borehole in order to prevent dusting. When this ceased, the EC-value increased rapidly to c. 1,100 mS/m and remained stable. The final water inflow at 200.50 m drilling length amounted to 64 L/min.

During drilling and sampling in borehole HFR102, a minor groundwater inflow was observed as damp recovered drilling debris until full drilling length at 55.04 m. The low water yield was confirmed by groundwater level measurements, see Figure 5-19, showing that it took several days after completed drilling for the groundwater table to recover to a level equal to that of the sea-level.

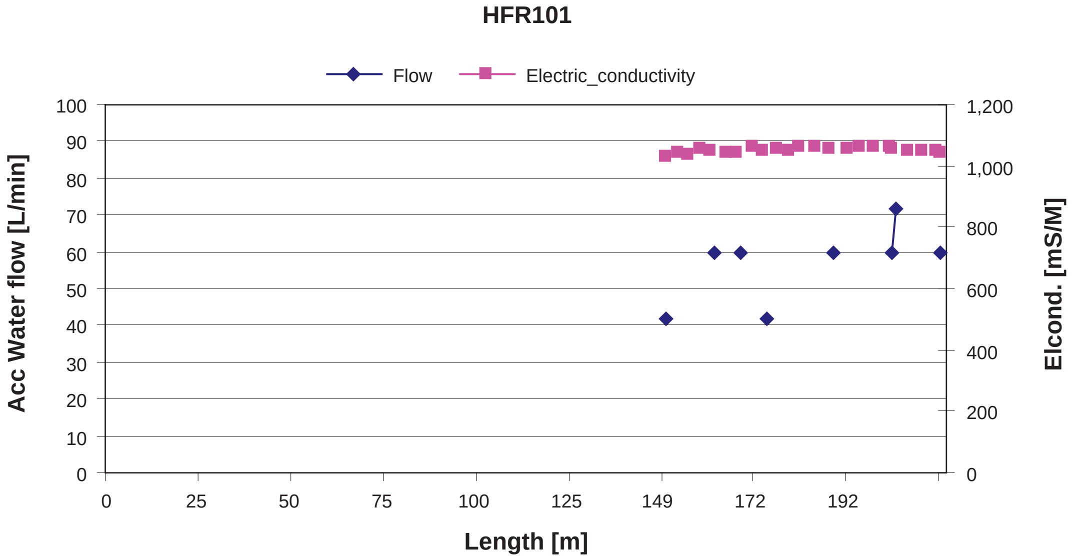


Figure 5-17. Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFR101.

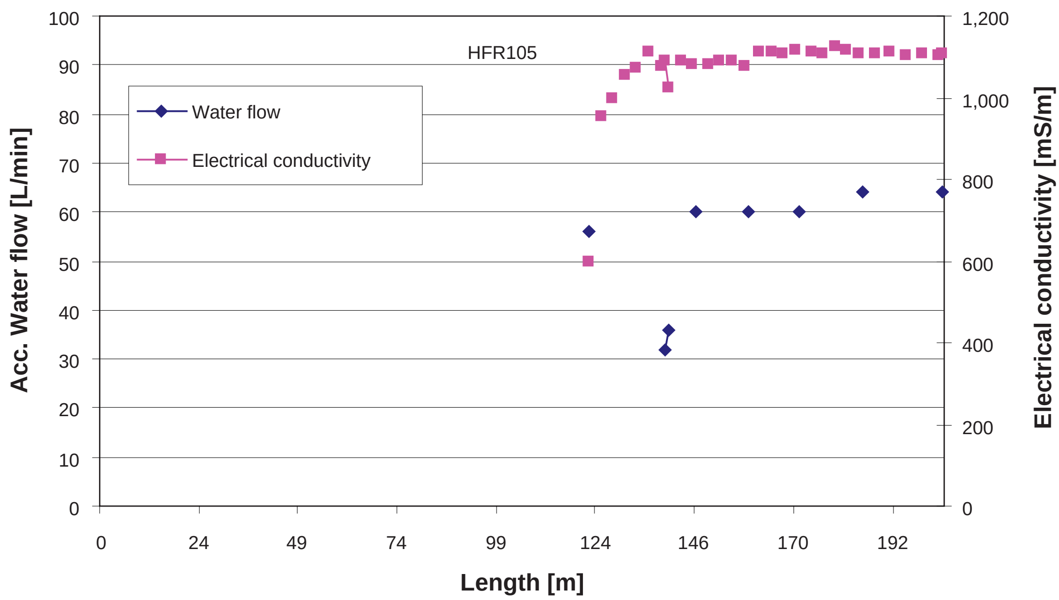


Figure 5-18. *Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFR105.*

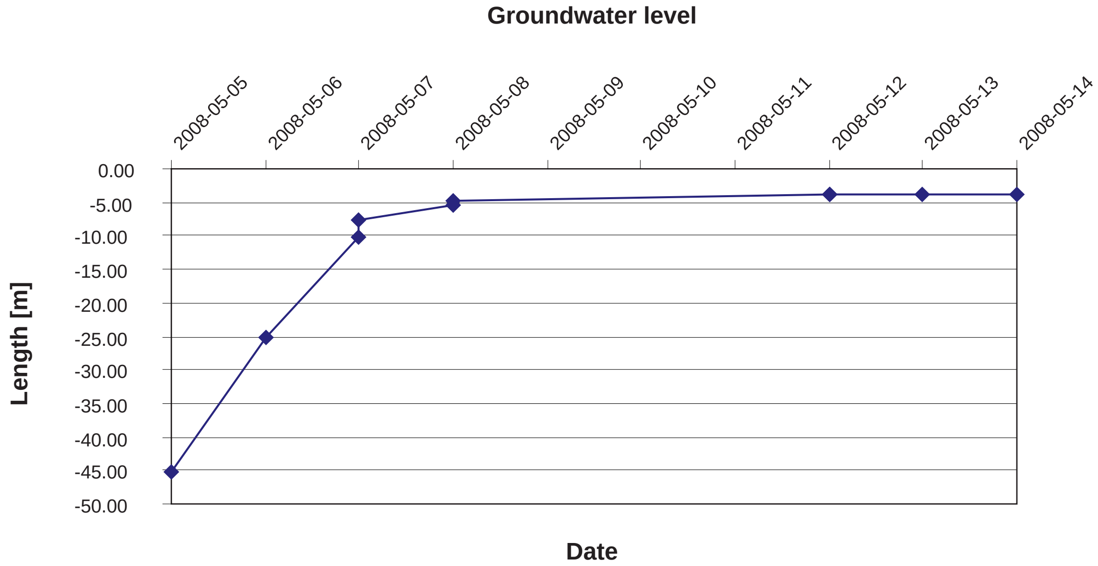


Figure 5-19. *Recovery of groundwater table after completed drilling of HFR102.*

References

/1/ **SKB, 2008.** Undersökningsprogram för Projekt SFR-utbyggnad (Investigation programme for the extension of SFR). SKB R-08-67, Svensk Kärnbränslehantering AB.

/2/ **SKB, 2008.** Site investigations. Investigation methods and general execution programme, SKB TR-01-29, Svensk Kärnbränslehantering AB.

/3/ **Döse C, 2008.** Boremap mapping of percussion drilled boreholes HFR101, HFR102 and HFR105 and core drilled borehole KFR27 (old part) in progress.

/4/ **Munier R, Stigsson M, 2007.** Implementation of uncertainties in borehole geometries and geological orientation data in Sicada. SKB R-07-19. Svensk Kärnbränslehantering AB.

/5/ **Follin S, Levén J, Hartley L, Jackson P, Joyce S, Roberts D, Swift B, 2007.** Hydrogeological characterisation and modelling of deformation zones and fracture domains, Forsmark modelling stage 2.2. SKB R-07-48, Svensk Kärnbränslehantering AB.