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Forsmark site investigation

Geophysical borehole logging in borehole KFM12A

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

Data in SKB's database can be changed for different reasons. Minor changes in SKB's database will not necessarily result in a revised report. Data revisions may also be presented as supplements, available at www.skb.se.

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Abstract

Geophysical borehole logging has been performed in borehole KFM12A situated in Forsmark, Sweden.

The objective of the survey is to determine the physical properties of the rock mass around the borehole, e.g. to determine rock types and quantify the fracture frequency and localise deformation zones in the rock. Geophysical borehole logging was used to measure changes in physical properties in the borehole fluid and the bedrock surrounding the boreholes.

The borehole KFM12A was recorded from Top Of Casing (TOC) to app. 600 m.

The present report comprises a description of the applied equipment and the performed logging program, the field work, data delivery and a presentation and discussion of the results.

Composite sheets of all the processed logs are included in Appendix 1.

Sammanfattning

Geofysisk borrhålsloggning har genomförts i borrhålet KFM12A i Forsmark.

Syftet med geofysisk borrhålsloggning är att bestämma bergets fysikaliska egenskaper för att bestämma bergartsfördelningen i det genomborrade bergpartiet, samt att kvantifiera sprickfrekvensen och att lokalisera deformationszoner. Med geofysisk borrhålsloggning mäts bergets och borrhålsvattnets fysikaliska egenskaper i borrhålet och omgivande berg.

Den geofysiska borrhålsloggningen genomfördes i KFM12A från TOC till ca. 600 m.

Rapporten beskriver använd utrustning, genomfört loggningsprogram, fältarbete, leverans av data och en diskussion av resultatet.

Processerade loggar presenteras i Appendix 1.

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1 Introduction

This document reports the results gained by the geophysical borehole logging in the borehole KFM12A, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with the activity plan AP PF 400-07-022 (SKB internal controlling document). In Table 1-1 controlling documents for performing this activity are listed.

All measurements were conducted by RAMBØLL during the period March 14 to 16, 2007. The borehole was recorded from Top Of Casing (TOC) to the bottom of the borehole. The technical data from the borehole is shown in Table 1-2. The location of the borehole is shown in Figure 1-1 and the technical data of the borehole is displayed in Figure 1-2.

The delivered raw and processed data have been inserted in the database of SKB (SICADA) and data are traceable by the activity plan number.

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the Activity Plan number (AP PF 400-07-022). 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.

Table 1-1. Controlling documents for the performance of the activity (SKB internal controlling documents).

| Activity plan | Number | Version |
|--|------------------|----------------|
| AP PF 400-07-022 Geofysisk borrhålsloggning i KFM12A ver 1.0.doc | AP PF 400-07-022 | 1.0 |
| Method descriptions | Number | Version |
| Metodbeskrivning för geofysisk borrhålsloggning | SKB MD 221.002 | 3.0 |
| Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål | SKB MD 224.001 | 1.0 |

Table 1-2. Technical data for borehole KFM12A.

| Borehole parameter | KFM12A |
|-------------------------------|----------------------------------|
| Co-ordinates (RT90) | X: 6696576.850 Y: 1630051.636 |
| Elevation (RHB70) | Z: 10.737 |
| Inclination (from horizontal) | -60.7° |
| Azimuth | 36.2° |
| Length [m] | 601.04 |
| Casing [m] | 59.45 |
| Borehole diameter [mm] | 77.3 |
| Cleaning level | Level 1 |

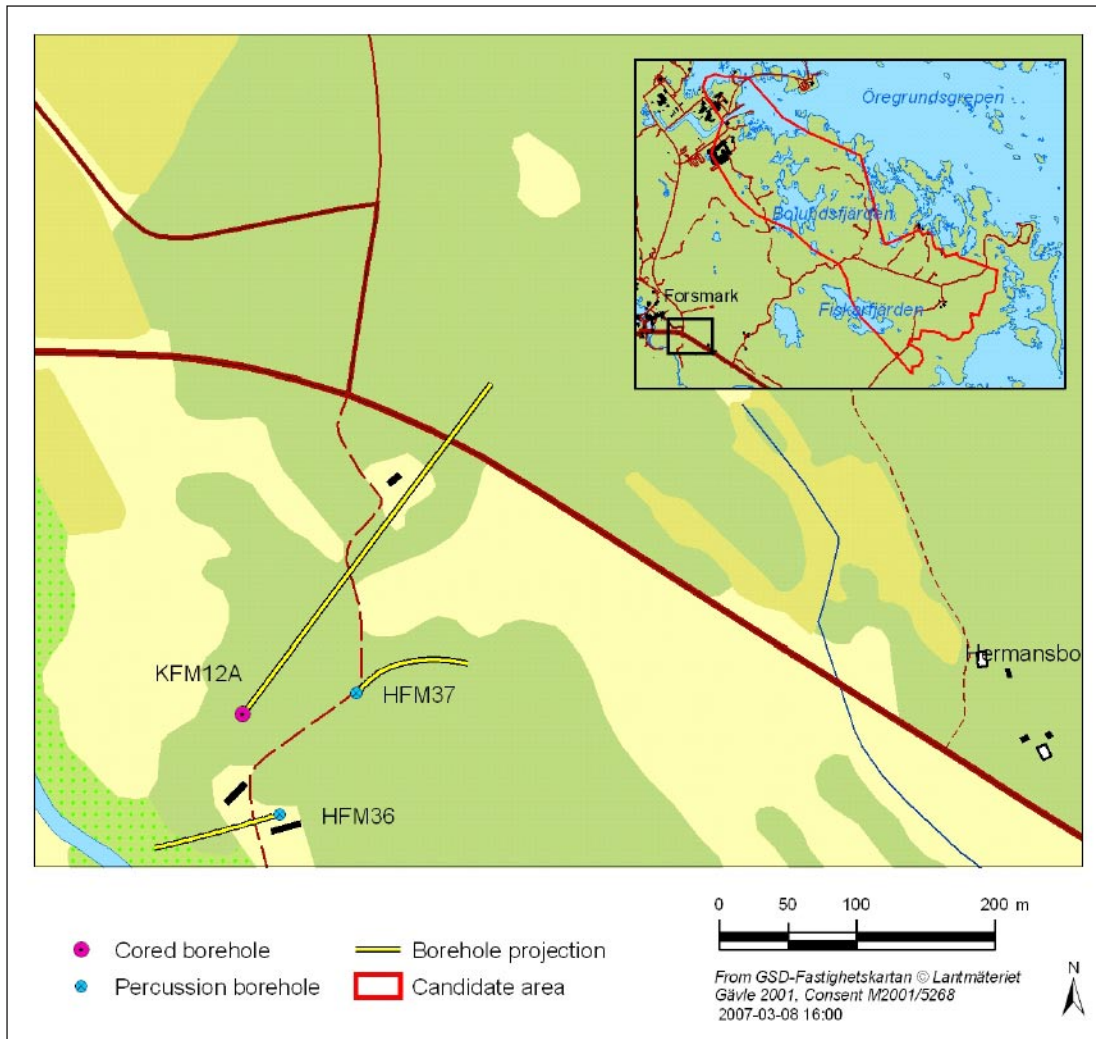


Figure 1-1. General overview over the Forsmark area showing the location of the borehole KFM12A.

Technical data

Borehole KFM12A

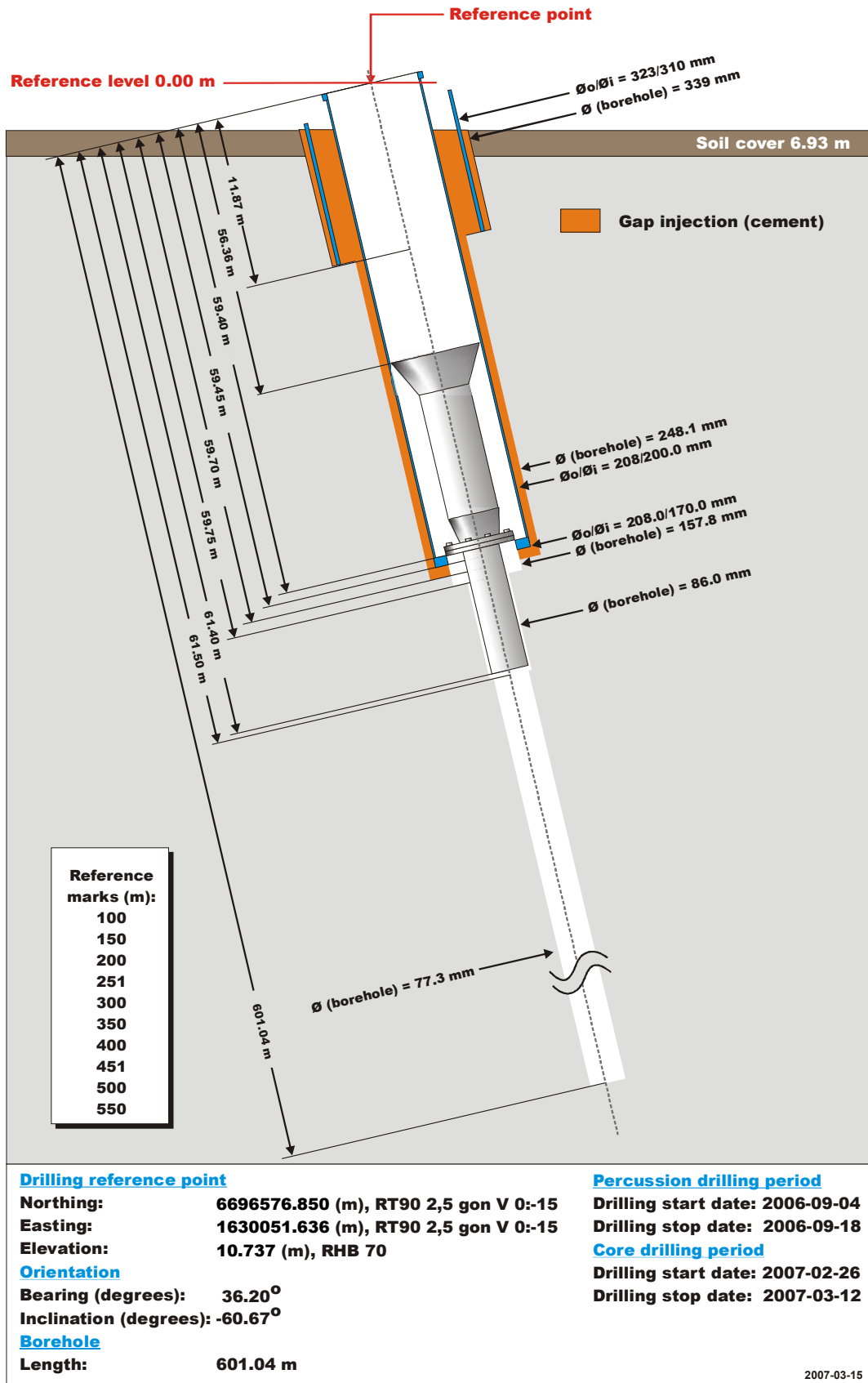


Figure 1-2. Technical description of borehole KFM12A.

2 Objective and scope

The objective of the survey is to both receive information of the borehole itself, and from the rock mass around the borehole. Geophysical borehole logging was used to measure changes in physical properties in the borehole fluid and the bedrock surrounding the borehole. Acoustic televiewer was used for determination of the deviation of the borehole (azimuth and inclination) as well as to determine the length marks in the borehole.

This field report describes the equipment used as well as the measurement procedures. Geophysical borehole logging data is presented in graphs as a function of borehole length on drawings shown in Appendix 1.

3 Equipment

The geophysical borehole logging program were performed with 7 multi tool probes and resulted in a suite of 16 log types. The tools and recorded logs are listed in Table 3-1 and the log types are listed in Table 5-1.

Table 3-1. Logging tools and logs recorded.

| Tool | Recorded logs | Dimension | Source detector spacing and type | Tool position in borehole |
|--|--|--------------|-----------------------------------|------------------------------------|
| Century 8144 Normal resistivity | Normal resistivity (16 and 64 inch), single point resistance and natural gamma. | 237-5.3 cm | | |
| Century 8622 Magnetic susceptibility | Magnetic susceptibility, natural gamma. | 203-4.1 cm | | |
| Century 9042 Fluid temperatur and fluid resistivity | Fluid temperatur, fluid resistivity and natural gamma. | 137-4.1 cm | | |
| Century 9072 3 m focused guard. | 3 m focused guard log resistivity and natural gamma. | 310-6.4 cm | | |
| Century 9139 Compensated gamma density. | Compensated Gamma density, natural gamma, 140 cm focused guard log resistivity, 1-arm caliper. | 380.3-5.6 cm | 20.3 cm 125 m 200 mCi Cs137 | Sidewall. Gamma source focused. |
| Century 9310 Sonic. | Full wave form travel-time providing P- and S-wave velocity picking, compensated P-wave travel-time and natural gamma. | 300-6.0 cm | Near 91.4 cm Far 121.9 cm | Centralized. |
| RG 25 112 000 HiRAT. Acoustic televiewer. | Full waveform acoustic amplitude and travel-time, 360° orientated acoustic image, 360° very high resolution caliper, borehole azimuth and dip and natural gamma. | 246-4 cm | | Centralized. |

4 Execution

4.1 General

In general, the measurement procedures follow the SKB method description (MD 221.002, SKB internal controlling document). The logging program was executed in the period March 14 to 16, 2007. All relevant logging events are described in the daily report sheets delivered to Sicada and are traceable by the activity plan number.

The fluid resistivity and temperature logs are recorded in downward direction, as the first log run. All other log types are recorded running the tool in upward direction in the borehole.

The applied logging equipment was calibrated and cleaned before arriving at the site according to SKB cleaning level 1 (SKB internal controlling document SKB MD 600.004). Furthermore, all equipment was wiped with alcohol before it was lowered into the borehole.

For control, each log run is normally recorded both in down and in upward direction using the down run as a repeat section. For logging tool 9139 recording a repeat section in upward direction controls the data. The depth of the probe in the borehole is shown on both the recording computer and the winch. On the winch the tension of the cable is also shown. The winch will automatically stop, if the tension changes rapidly. The tension was recorded on all log runs using Century equipment, except tool 9310.

All data was recorded with max. 10 cm sample interval. The speed of the logging for the 9139 tool was 5 m/min, for the 8622 tool 20 m/min and for all other tools 10 m/min, except for the HiRAT Acoustic tool where the speed was 2 m/min.

4.2 Nonconformities

No nonconformities are reported. The logging has been performed in accordance with the activity plan AP PF 400-07-022.

5 Results

5.1 Presentation

All relevant logging events were described in the daily report sheets, which were delivered separately.

The logs presented in drawing no. 1.1 (Appendix 1) are listed in Table 5-1.

5.2 Orientation, alignment and stretch of logs

5.2.1 Orientation of images

The orientation of the results from the HiRAT Acoustic tool, are processed in the tool while recording, using the magnetometers and accelerometers in the tool.

5.2.2 Overlapping data

If the log data from one probe have been recorded in more than one file, the files are merged using events in both files. Overlapping in data is always used from the topmost-recorded file (overlapping data are never presented as the mean value from two log runs).

Table 5-1. Logs presented in drawing no. 1.1 in Appendix 1.

| Log | Log name short | Unit | Tool |
|---------------------------------------|----------------|---------------------|-------|
| Fluid temperature | TEMP(FL) | Deg C | 9042 |
| Fluid resistivity | RES(FL) | Ohm-m | 9042 |
| Normal resistivity 16 inch | RES(16N) | Ohm-m | 8144 |
| Normal resistivity 64 inch | RES(64N) | Ohm-m | 8144 |
| Lateral resistivity | LATERAL | Ohm-m | 8144 |
| Single point resistance | SPR | Ohm | 8144 |
| Self potential | SP | mV | 8144 |
| Magnetic susceptibility | MAGSUSCEP | SI·10 ⁻⁵ | 8622 |
| Caliper, 1-arm | CALIPER1 | mm | 9139 |
| Gamma-gamma density | DENSITY | kg/m ³ | 9139 |
| Focused guard log resistivity, 127 cm | RES(SG) | Ohm-m | 9139 |
| Natural gamma | GAM(NAT) | µR/h | 9072 |
| Natural gamma | GAM(NAT) | µR/h | HIRAT |
| Focused guard log resistivity, 300 cm | RES(DG) | Ohm-m | 9072 |
| P-wave velocity | P-VEL | m/s | 9310 |
| Full wave form, near receiver | AMP(N) | µs | 9310 |
| Full wave form, far receiver | AMP(F) | µs | 9310 |
| Caliper, high resolution. 360° | CALIPER 3D | mm | HiRAT |
| High resolution 1D Caliper | CALIPER MEAN | mm | HiRAT |
| Borehole azimuth magnetic north | AZIMUTH MN | Deg | HIRAT |
| Borehole inclination from horizontal | DIP | Deg | HIRAT |
| 360° orientated acoustic travel time | TRAVEL TIME | 100 ns | HiRAT |
| 360° orientated acoustic travel time | AMPLITUDE | – | HiRAT |

5.2.3 Alignment of data

In order to obtain an exact length calibration, the track marks made while drilling are used. In boreholes without track marks, gamma events in the top and the bottom of the borehole are used. The connection between the track marks and the logs is obtained from the HiRAT Acoustic tool. The depths from the track marks and from the HiRAT tool are used to make a new depth scale in WellCAD. All log files are shifted using the new length scale.

5.2.4 Stretch of logs

There is a minor difference in the length registration between up- and down runs for the used winch. The size of the defect is about 1.5 m/km. To compensate for this the logs are stretched using another new length scale for each tool. The length scale is constructed by comparing gamma events from the actual tool with the same gamma events from the HiRAT tool. The events in both files are matched, and the new length scale is made and added to the log. The logs are stretched to the bottom of the borehole to ensure that no data will occur below the bottom of the borehole.

5.2.5 Removing of data

The processing of the data includes removing of spikes, negative and unrealistic values and data in the casing.

5.2.6 Repicking of sonic log

The sonic velocity is normally calculated using an automatic picking routine in the sonic tool, 9310. In inclined boreholes the routine is often picking the wrong arrivals, due to so-called “road noise”. Therefore the sonic logs have been manually repicked in WellCAD using the full wave signal.

5.3 Calculated log curves

The different logs are calculated as described in Table 5-2.

5.3.1 Calculation of coordinates

To convert the measured azimuth and inclination to RT90, one needs to take into account the magnetic declination at the site at the time of data acquisition. The actual declination was found by means of the current International Geomagnetic Reference Field (IGRF). Disturbances from solar storms etc were not taken into account. By means of the “Radius Of Curvature” method implemented in WellCad, the azimuth and inclination were converted to coordinates relative to the TOC. In the same calculation, the magnetic declination was added. Finally, the relative coordinates were added to the given coordinates in RT90 for the TOC. The coordinates were calculated from 5 m below the casing bottom.

5.4 Borehole KFM12A

In order to obtain an exact length calibration in borehole KFM12A, the reference track marks made while drilling are used. The correlation between the track marks and the logs is obtained from the HiRAT Acoustic tool.

The reference track marks in the borehole and the corresponding recorded track marks from the HiRAT are listed in Table 5-3.

Table 5-2. Calculated log curves.

| Log | Description of log calculation |
|---|--|
| Caliper, 1-arm | The Caliper was converted from [cm] to [mm] units by multiplying [cm] with 10. |
| Gamma-gamma density | The Gamma-gamma was converted from [g/cm ³] to [kg/m ³] units by multiplying with 1,000. |
| Focused guard log resistivity, 140 cm | – |
| Natural gamma | The natural gamma log was converted from CPS to μ R/h by multiplying the constant 0.077. This constant was computed from the logs previously performed in borehole KLX02 located in Oskarshamn. |
| Fluid temperature | – |
| Fluid resistivity | – |
| Normal resistivity 16 inch | – |
| Normal resistivity 64 inch | – |
| Lateral resistivity | – |
| Single point resistance | – |
| Self-potential | The SP value was converted from [mV] to [V] by dividing with 1,000. |
| Focused guard log resistivity, 300 cm | – |
| P-wave velocity | The P-VEL velocity is calculated using the difference in distance between the far and near receiver divided by time difference between the first arrival from the far and near signal. (121.9 cm – 91.4 cm)/(Time(far) – Time(near)). |
| Full wave form, near receiver | – |
| Full wave form, far receiver | – |
| Magnetic susceptibility | The magnetic susceptibility was converted for CGS units to SI units by multiplying the CGS value by 4π . |
| Caliper, high resolution. 360°. CALIPER 3D | The Caliper 3D is calculated using the acoustic travel time and the velocity in the borehole fluid. The velocity in the fluid is calculated using the fluid temperature and fluid conductivity. |
| High resolution 1D Caliper CALIPER MEAN | The Caliper mean is calculated using the mean travel time from the acoustic televiewer, the fluid temperature, fluid velocity and the internal travel time in the acoustic televiewer. |
| Borehole azimuth magnetic north | See 5.3.1 |
| Borehole Inclination from lateral | See 5.3.1 |
| 360° orientated acoustic travel time | – |
| 360° orientated acoustic amplitude | – |

Table 5-3. The reference track marks in the borehole and the recorded track marks from the HIRAT in borehole KFM12A.

| Reference mark | HIRAT recorded |
|----------------|----------------|
| 61.40 | 61.4 |
| 100.00 | 100.13 |
| 150.00 | 150.295 |
| 200.00 | 200.503 |
| 251.00 | 251.615 |
| 300.00 | 300.769 |
| 350.00 | 350.902 |
| 400.00 | 401.000 |
| 451.00 | 452.176 |
| 500.00 | 501.341 |
| 550.00 | 551.452 |

To compensate for the difference between the reference track marks and the recorded track marks the logs are stretched. The result from the stretching is a new length scale. The new length scale is applied to the HiRAT file. In this way a perfect match between the reference marks and the recorded data is obtained. By means of alignment of the observed gamma events in KFM12A, between all log runs, the obtained reference mark correlation is transferred to the other logs.

The complete log suite for borehole KFM12A is presented as composite log sheets in drawing 1.1 in Appendix 1. The logs presented in drawing no. 1.1 are listed in Table 5-1.

6 Data delivery

Geophysical logging data from the measurements, recorded in Century and Robertson format, were delivered directly after the termination of the field activities. The recorded data files used in the processing have also been delivered in WellCAD format, Table 6-1.

The delivered data have been inserted in the database (Sicada) of SKB and are traceable by the activity plan number.

The processed files shown on the drawings have been delivered in WellCAD, Table 6-2, and as excel files in Sicada format, Table 6-3.

Table 6-1. Recorded log files in Century or Robertson format used for processing.

| Borehole | Probe | Log direction | WellCAD File | Description |
|----------|-------|---------------|--|--|
| KFM12A | 8144 | Up | KFM12A_03-14-07_09-53_8144C_02_0.90_601.10_ORIG.log | Start Depth: 601.1 m. End Depth: 0.9 m |
| KFM12A | 9042 | Down | KFM12A_03-14-07_07-40_9042C_02_0.22_600.34_ORIG.log | Start Depth: 0.22 m. End Depth: 600.34 m |
| KFM12A | 9072 | Up | KFM12A_03-14-07_15-45_9072C_02_0.02_600.68_ORIG.log | Start Depth: 600.68 m. End Depth: 0.02 m |
| KFM12A | 9139 | Up | KFM12A_03-14-07_17-23_9139A_02_56.48_599.29_ORIG.log | Start Depth: 599.29 m. End Depth: 56.48 m |
| KFM12A | 9310 | Up | KFM12A_03-15-07_08-02_9310C2_02_3.40_599.83_ORIG.log | Start Depth: 599.83 m. End Depth: 3.4 m |
| KFM12A | HiRAT | Up | KFM12A_HiRAT_120pixels_up_unaligned_run2.HED | Start Depth: 598 m. End Depth: 55 m |

Table 6-2. Drawing files in WellCad format.

| Borehole | Drawing | WellCad file |
|----------|---------|-------------------------|
| KFM12A | 1.1 | KFM12A_Presentation.WCL |

Table 6-3. Data files in SICADA format.

| Sheet | Comment |
|---|---------|
| "Borehole"_CALIPER1_GP040 - Caliper logging.xls | |
| "Borehole"_CALIPER MEAN_GP041 - 3-D caliper.xls | |
| "Borehole"_TEMP(FL)_RES(FL)_GP060 – Fluid temperature and resistivity logging.xls | |
| "Borehole"_DENSITY_GP090 – Density logging.xls | |
| "Borehole"_MAGSUSCEP_GP110 - Magnetic susceptibility logging.xls | |
| "Borehole"_GAM(NAT)_GP120 - Natural gamma logging.xls | |
| "Borehole"_SPR_GP150 - Single point resistance logging.xls | |
| "Borehole"_RES(64N)_GP160 - Resistivity, normal 1.6 m (64 in).xls | |
| "Borehole"_RES(MG)_GP161 - Resistivity, focused 140 cm.xls | |
| "Borehole"_RES(DG)_GP162 - Resistivity, focused 300 cm.xls | |
| "Borehole"_LATERAL_GP163 - Resistivity, lateral 1.6-0.1 m.xls | |
| "Borehole"_RES(16N)_GP164 - Resistivity, normal 0.4 m (16 in).xls | |
| "Borehole"_P-VEL_GP175 - Fullwave sonic.xls | |
| "Borehole"_GP830 - Acoustic televiewer.xls | |
| "Borehole"_SP_GP180 - Self potential logging.xls | |

Borehole KFM12A. Drawing no. 1.1. Borehole logs


Co-ordinates in RT90 2,5 gon V 0:-15

Northing: 6696576.85m Easting: 1630051.636m Elevation: 10.737m, RHB70

Diameter: 77.3mm
 Reaming Diameter: 248.1mm
 Outer Casing: 86mm
 Inner Casing: 80mm
 Casing Length: 61.4m
 Borehole Length: 601.04m
 Cone:
 Inclination at ground surface: -60.67°
 Azimuth: 36.2° GN
 Comments:

Borehole logging programme

| Name | Description | Tool | Unit |
|--------------|---|-------|-------------------|
| CALIPER1 | Caliper, 1-arm | 9139 | mm |
| DENSITY | Gamma-gamma density | 9139 | kg/m ³ |
| RES(SG) | Focused guard log resistivity, 128 cm | 9139 | ohm-m |
| GAM(NAT) | Natural gamma | 9072 | µR/h |
| TEMP(FL) | Fluid temperature | 9042 | deg C |
| RES(FL) | Fluid resistivity | 9042 | ohm-m |
| RES(DG) | Focused guard log resistivity, 300cm | 9072 | ohm-m |
| P-VEL | P-wave velocity | 9310 | m/s |
| AMP(N) | Full wave form, near receiver | 9310 | µs |
| AMP(F) | Full wave form, far receiver | 9310 | µs |
| MAGSUSCEP | Magnetic susceptibility | 8622 | SI*10-5 |
| CALIPER 3D | Caliper, high resolution 360 degrees | HiRAT | mm |
| CALIPER MEAN | High resolution 1D caliper | HiRAT | mm |
| AZIMUTH MN | Borehole azimuth magnetic north | HiRAT | deg |
| DIP | Borehole inclination from horizontal | HiRAT | deg |
| RADIUS | 360 degrees orientated acoustic radius | HiRAT | mm |
| AMPLITUDE | 360 degrees orientated acoustic amplitude | HiRAT | - |
| THORIUM | Spectral gamma, Thorium component | 9080 | PPM |
| URANIUM | Spectral gamma, Uranium component | 9080 | PPM |
| POTASSIUM | Spectral gamma, Potassium component | 9080 | percent |
| RES(16N) | Normal resistivity 16 inch | 8144 | ohm-m |
| RES(64N) | Normal resistivity 64 inch | 8144 | ohm-m |
| LATERAL | Lateral resistivity | 8144 | ohm-m |
| SPR | Single point resistivity | 8144 | ohm |
| SP | Self Potential | 8144 | V |

| | | | | | |
|--|---------------------------|------------------------|-----------------------|------------------------|--|
| Rev. 0 | Date 2007-03-19 | Drawn by JRI | Control UTN | Approved UTN |  <small>Ramboll, Bredevej 2, DK-2830 Virum Phone + 45 45 98 60 00, Fax + 45 45 98 67 00</small> |
| Job 547310A | Scale 1:500 | | | | |
| <hr/> <h2>SKB geophysical borehole logging</h2> <h3>Borehole KFM12A</h3> <hr/> <p>Presentation</p> | | | | | Filename: KFM12A_Presentation.wcl Drawing no.: 1.1 |

