P-05-53

Forsmark site investigation

RAMAC and BIPS logging in borehole KFM06B

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March 2005

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Keywords: BIPS, RAMAC, radar, TV, Forsmark, AP PF 400-04-47.

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.

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Abstract

This report includes the data gained in geophysical logging operations performed within the site investigation at Forsmark. The logging operations presented here includes BIPS logging and borehole radar (RAMAC) and in the core-drilled borehole KFM06B. All measurements were conducted by Malå Geoscience AB / RAYCON during February 2005.

The objective of the radar surveys is to achieve information on the rock mass around the borehole. Borehole radar is used to investigate the nature and the structure of the rock mass enclosing the boreholes.

The objective of the BIPS logging is to achieve information of the borehole including occurrence of rock types as well as determination of fracture distribution and orientation.

This report describes the equipment used as well as the measurement procedures and data gained. For the BIPS survey, the result is presented as images. Radar data is presented in radargrams and the identified reflectors are listed.

The borehole radar data quality from KFM06B was satisfying, but in some minor parts of lower quality due to more conductive conditions. This conductive environment of course reduces the possibility to distinguish and interpret possible structures in the rock mass which otherwise could give a reflection. However, the borehole radar measurements resulted in a number of identified radar reflectors. 27 reflectors were identified in KFM06B, and 8 of them oriented.

The basic conditions of the BIPS logging for geological mapping and orientation of structures are very good for borehole KFM06B.

Sammanfattning

Denna rapport omfattar geofysiska loggningar inom platsundersökningsprogrammet för Forsmark. Mätningarna som presenteras här omfattar BIPS-loggningar i borrhålen KFM06B. Alla mätningar är utförda av Malå Geoscience AB / RAYCON under februari 2005.

Syftet med radarmätningarna är att samla information om bergmassan runt borrhålet. Borrhålsradar används till att karakterisera bergets egenskaper och strukturer i bergmassan närmast borrhålet.

Syftet med BIPS loggningen är att skaffa information om borrhålet inkluderande förekommande bergarter och bestämning av sprickors fördelning och deras orientering.

Rapporten beskriver utrustningen som använts liksom mätprocedurer och en beskrivning och tolkning av data som erhållits. För BIPS loggningen presenteras data som plottar längs med borrhålet. Radardata presenteras i radargram och en lista över tolkade radarreflektorer ges.

Borrhålsradardata från KFM06B var tillfredställande, men i delar av sämre kvalité troligen till stor del beroende på en konduktiv miljö. En konduktiv miljö minskar möjligheterna att identifiera strukturer från borrhålsradardata. 27 radarreflektorer har identifierats i KFM06B, varav 8 är orienterade.

BIPS bilderna visar att förutsättningarna för geologisk kartering och sprickorientering är mycket goda för KFM06B.

Contents

1 Introduction

This document reports the data gained in geophysical logging operations, which is one of the activities performed within the site investigation at Forsmark. The logging operations presented here includes borehole radar (RAMAC) and TV-logging (BIPS) in the core-drilled borehole KFM06B. The work was carried out in accordance with the activity plan AP PF 400-04-47. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB’s internal controlling documents.

This report includes measurements from 0 to approximately 100 m in borehole KFM06B. The borehole is drilled near-vertical (85 degrees from the horizontal) with a direction of 300 degrees and a diameter of approximately 76 mm.

All measurements were conducted by Malå Geoscience AB/RAYCON during February 2005. The location of the borehole is shown in Figure 1-1.

The used investigation techniques comprised:

- Borehole radar measurements (Malå Geoscience AB:s RAMAC system) with dipole and directional antennas.
- Borehole TV logging with the so-called BIPS-system (Borehole Image Processing System), which is a high resolution, side viewing, colour borehole TV system.

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

Activity plan	Number	Version
Borrhålsloggning med BIPS och Radar i teleskopborrhålen KFM05A och KFM06A (100–1,000 m) samt KFM06B (0–100 m)	AP PF 400-04-47	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för TV-loggning med BIPS	SKB MD 222.006	1.0
Metodbeskrivning för borrhålsradar	SKB MD 252.020	1.0

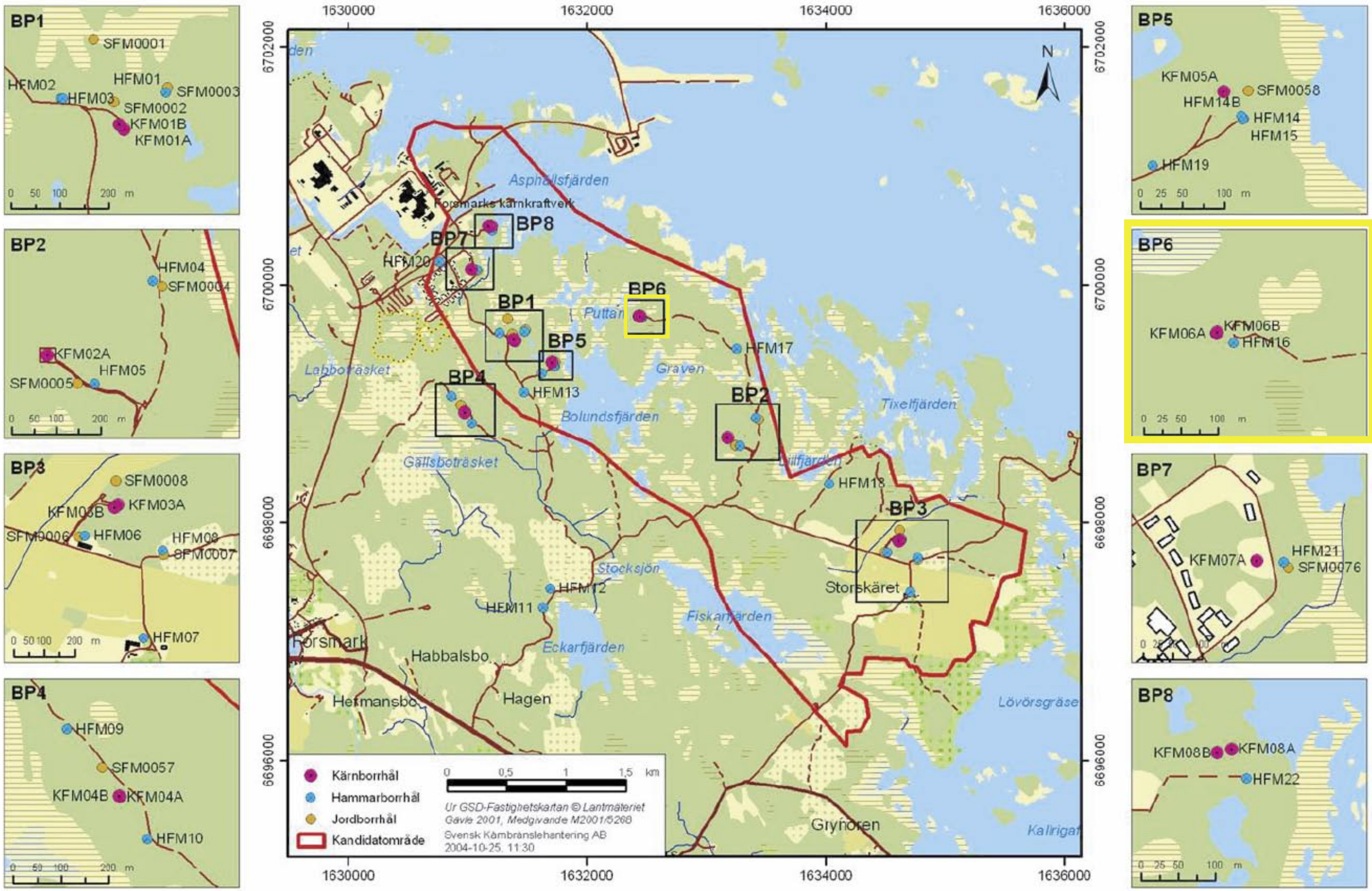


Figure 1-1. *General overview over the Forsmark area with the location of the borehole KFM06B.*

2 Objective and scope

The objective of the radar and BIPS surveys is to achieve information on the borehole conditions (borehole wall) as well as on the rock mass around the borehole. Borehole radar is engaged to investigate the nature and the structure of the rock mass enclosing the boreholes, and borehole TV for geological surveying of the borehole including determination of fracture distribution and orientation.

This report describes the equipment used as well the measurement procedures and data gained. For the BIPS survey, the result is presented as images. Radar data is presented in radargrams and the identified reflectors are listed.

3 Equipment

3.1 Radar measurements RAMAC

The RAMAC GPR system owned by SKB is a fully digital GPR system where emphasis has been laid on fast survey speed and easy field operation. The system operates dipole and directional antennas (see Figure 3-1). A system description is given in the SKB internal controlling document MD 252.021.

The borehole radar system consists of a transmitter and a receiver antenna. During operation an electromagnetic pulse, within the frequency range of 20 MHz up to 250 MHz, is emitted into the bedrock. Once a feature, e.g. a water-filled fracture, with sufficiently different electrical properties is encountered, the pulse is reflected back to the receiver and recorded.

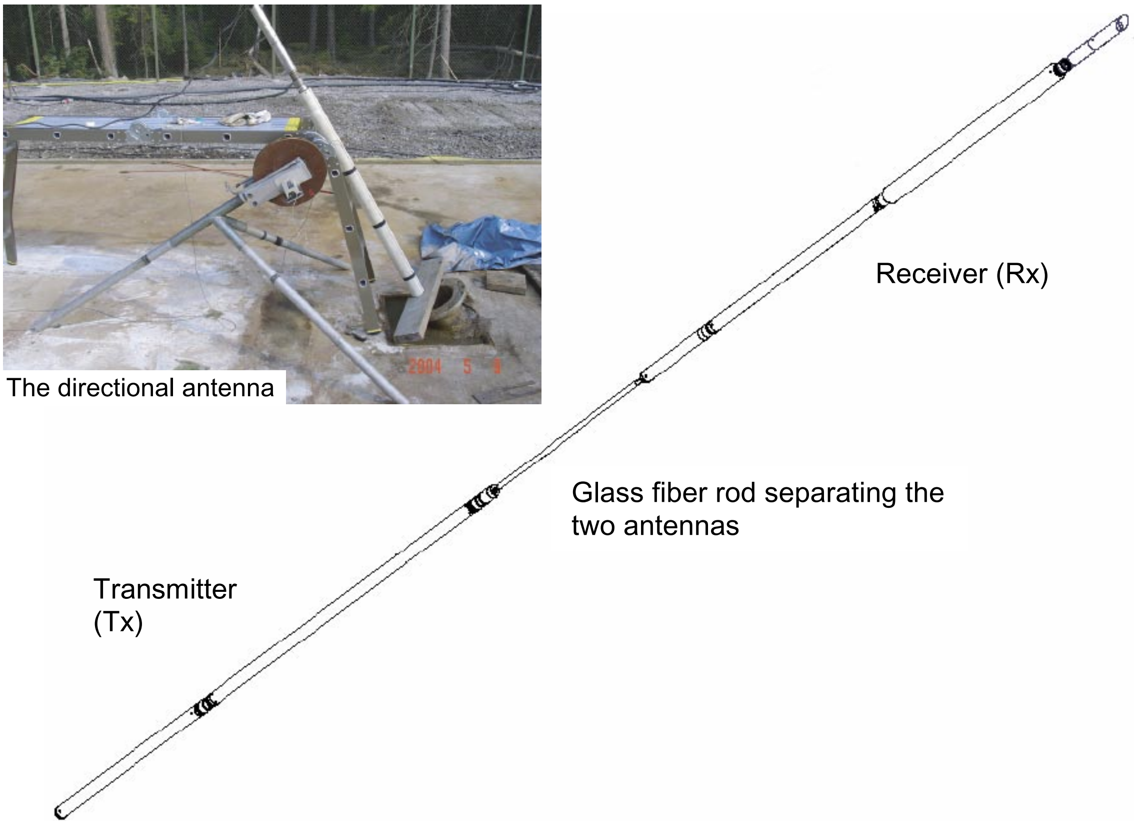


Figure 3-1. *Example of a borehole radar antenna.*

3.2 TV-Camera, BIPS

The BIPS 1500 system used is owned by SKB and described in SKB internal controlling document MD 222.005. The BIPS method for borehole logging produces a digital scan of the borehole wall. In principle, a standard CCD video camera is installed in the probe in front of a conical mirror (see Figure 3-2). An acrylic window covers the mirror part and the borehole image is reflected through the window and displayed on the cone, from where it is recorded. During the measuring operation, a circle of pixels is grabbed with a resolution of 360 pixels/circle.

The system orientates the BIPS images according to two alternative methods, either using a compass (vertical boreholes) or with a gravity sensor (inclined boreholes).

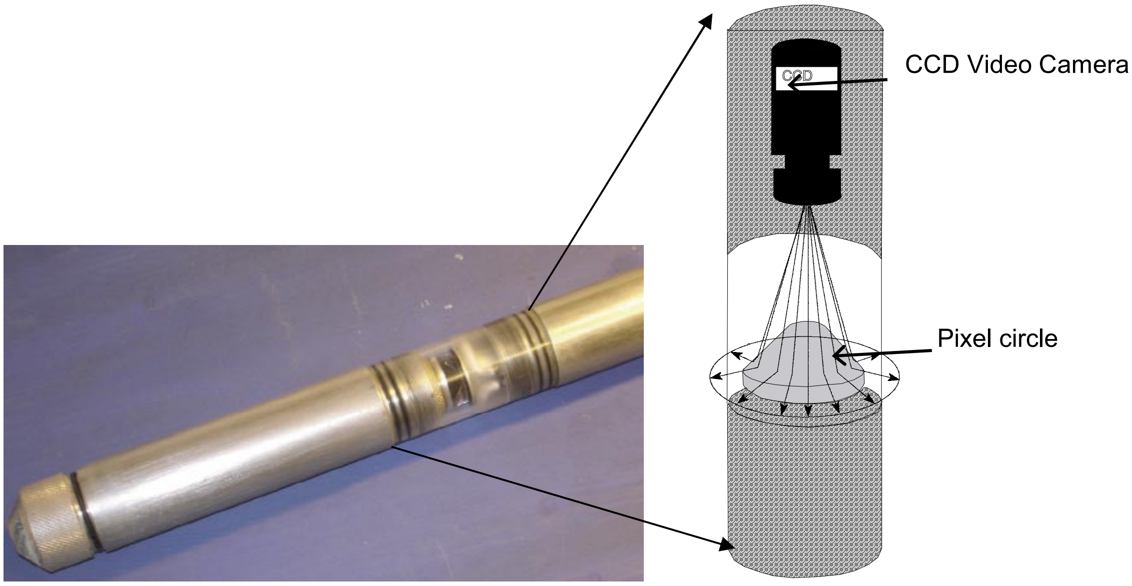


Figure 3-2. *The BIPS-system. To the right an illustration of the conical mirror scanning.*

4 Execution

4.1 General

4.1.1 RAMAC radar

The measurements in KFM06B were carried out with dipole radar antennas, with frequencies of 250, 100 and 20 MHz. The directional antenna was also used, with a central frequency of 60 MHz.

During logging the dipole antennas (transmitter and receiver) were lowered continuously into the borehole and data were recorded on a field PC along the measured interval. The measurement with the directional antenna is made step wise, with a short pause for each measurement occasion. The antennas (transmitter and receiver) are kept at a fixed separation by glass fiber rods according to Table 4-1. See also Figure 3-1 and 4-1.

All measurements were performed in accordance with the instructions and guidelines from SKB (internal document MD 252.020). All cleaning of the antennas and cable was performed according to the internal document SKB MD 600.004 before the logging operation.

The functionality of the directional antenna was tested before measurements in KFM06B. This is done by measurements in the air, where the receiver antenna and the transmitter antenna are placed apart. While transmitting and measuring, the receiver antenna is turned around and by that giving the direction from the receiver antenna to the transmitter antenna. The difference in direction measured by compass and the result achieved from the directional antenna was about 2 degrees. This can be considered as very good due to the disturbed environment, with metallic objects etc at the test site.

For more information on system settings used in the investigation of KFM06B see Table 4-1.

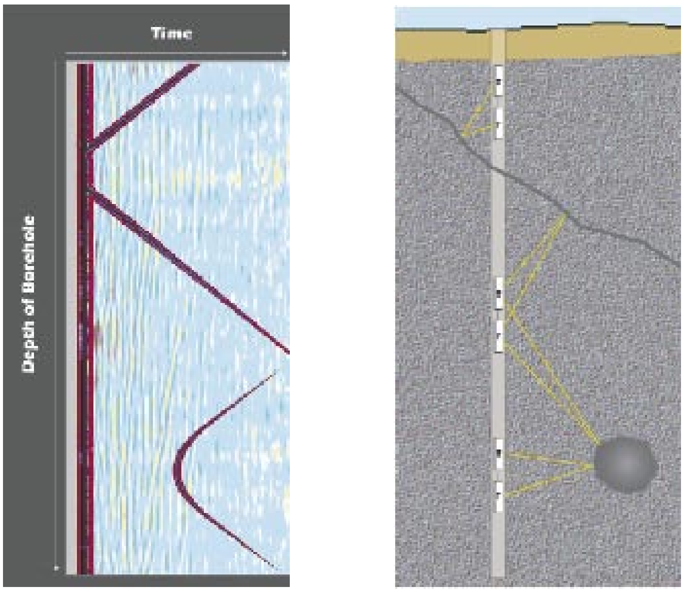


Figure 4-1. *The principle of radar borehole reflection survey and an example of result.*

Table 4-1. Radar logging information from KFM06B.

Site:	**Forsmark**	**Logging company:**		**RAYCON**	
BH:	**KFM06B**	**Equipment:**		**SKB RAMAC**	
Type:	**Directional/Dipole**	**Manufacturer:**		**MALÅ GeoScience**	
Operator:	**CG**	**Antenna**			
		Directional	**250 MHz**	**100 MHz**	**20 MHz**
	Logging date:	05-02-11	05-02-10	05-02-11	05-02-11
	Reference:	T.O.C.	T.O.C.	T.O.C.	T.O.C.
	Sampling frequency (MHz):	615	2,424	1,091	239
	Number of samples:	512	619	512	518
	Number of stacks:	32	Auto	Auto	Auto
	Signal position:	410.51	–0.30	–0.31	–1.40
	Logging from (m):	3.4	1.5	2.6	6.25
	Logging to (m):	91.4	97	96.5	92.25
	Trace interval (m):	0.5	0.25	0.2	0.1
	Antenna separation (m):	5.73	1.9	2.9	10.05

4.1.2 BIPS

All measurements were performed in accordance with the instructions and guidelines from SKB (internal document MD 222.006). All cleaning of the probe and cable was performed according to the internal document SKB MD 600.004 before the logging operation.

During the measurement, a circle of pixels with a resolution of 360 pixels/circle was used and the digital circles were stored at every 1 mm on a MO-disc in the surface unit. The maximum speed during data collection was 1.5 m/minute.

In order to control the quality of the system, calibration measurements were performed in a test pipe before logging the first borehole and after logging the last one. Figure 4-2 corresponds to the test pipe logging before and after the logging of KFM08B and KFM06B in February. The results showed no difference regarding the colours and focus of the images. Results of the test loggings were included in the delivery of the raw data.

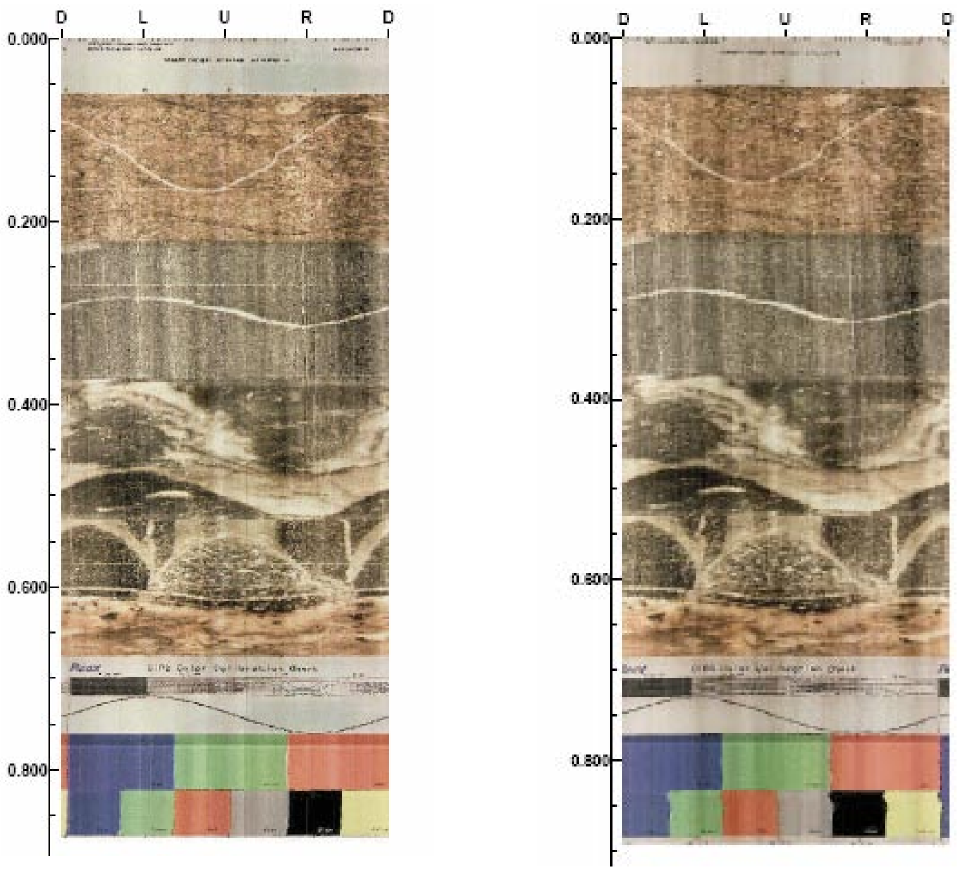
The BIPS logging information is found in the header presented in Appendix 2 in this report.

4.1.3 Length measurements

During logging the depth recording for the RAMAC and BIPS systems is taken care of by a measuring wheel mounted on the cable winch.

There are no marks created by the drill rig in this borehole. Therefore the length adjustment for the BIPS measurement is done from the empirical knowledge of the tension and other depth related errors. Based on previous experience the depth divergence is known to be less than about 50 cm for a 100 m deep borehole.

No depth adjustment is done to the radar results, as the borehole is less than 100 m deep, the depth divergence is very small (approximately 10 cm in the deepest parts).



Before **After**

Figure 4-2. *Results from logging in the test pipe before and after the logging campaign in February (05-02-09–05-02-11).*

4.2 Analyses and interpretation

4.2.1 Radar

The result from radar measurements is most often presented in the form of a radargram where the position of the probes is shown along one axis and the propagation is shown along the other axis. The amplitude of the received signal is shown in the radargram with a grey scale where black color corresponds to the large positive signals and white color to large negative signals. Grey color corresponds to no reflected signals.

The presented data in this report is adjusted for the measurement point of the antennas. The measurement point is defined to be the central point between the transmitter and the receiver antenna.

The two basic patterns to interpret in borehole measurements are point and plane reflectors. In the reflection mode, borehole radar essentially gives a high-resolution image of the rock mass, showing the geometry of plane structures which may or may not, intersect the borehole (contact between layers, thin marker beds, fractures) or showing the presence of local features around the borehole (cavities, lenses etc.).

The distance to a reflecting object or plane is determined by measuring the difference in arrival time between the direct and the reflected pulse. The basic assumption is that the speed of propagation is the same everywhere.

There are several ways to determine the radar wave propagation velocity. Each of them has its advantages and its disadvantages. In this project the velocity determination was performed by keeping the transmitter fixed in the borehole while moving the receiver downwards in the borehole. The result is plotted in Figure 4-3 and the calculation shows a velocity of 128 m/µs. The velocity measurement was performed with the 100 MHz antenna /1/.

The visualization of data in Appendix 1 is made with ReflexWin, a Windows based processing software for filtering and analysis of borehole radar data. The processing steps are shown in Table 4-2. It should be observed that the processing steps below refer to the Appendix 1. The filters applied affect the whole borehole length and are not always suitable in all parts, depending on the geological conditions and conductivity of the borehole fluid. During interpretation further processing can be done, most often in form of bandpass filtering. This filtering can be applied just in parts of the borehole, where needed.

The software RadInter SKB, is used for the interpretation of the intersection angle between the borehole axis and the planes visible on the radargrams. The interpreted intersection points and intersection angles of the detected structures are presented in the Tables 5-1 and 5-2 and are also visible on the radargrams in Appendix 1.

Table 4-2. Processing steps for borehole radar data from KFM06B.

Site:	**Forsmark**	**Logging company:**	**RAYCON**		
BH:	**KFM06B**	**Equipment:**	**SKB RAMAC**		
Type:	**Directional/Dipole**	**Manufacturer:**	**MALÅ GeoScience**		
Interpret:	**JA**	**Antenna**			
		Directional	**250 MHz**	**100 MHz**	**20 MHz**
Processing:		DC removal (340–511)	DC removal (170–240)	DC removal (380–500)	DC removal (1,600–2,030)
		Move start time (–70)	Move start time (–14.1)	Move start time (–34.9)	Move start time (–113.7)
		Gain (from 119, linear 100, exp)	Gain (from 16, linear 1.4, exp 1)	Gain (from 46, linear 1, exp 0.6)	Gain(from 129, linear 4.5, exp 0.13)

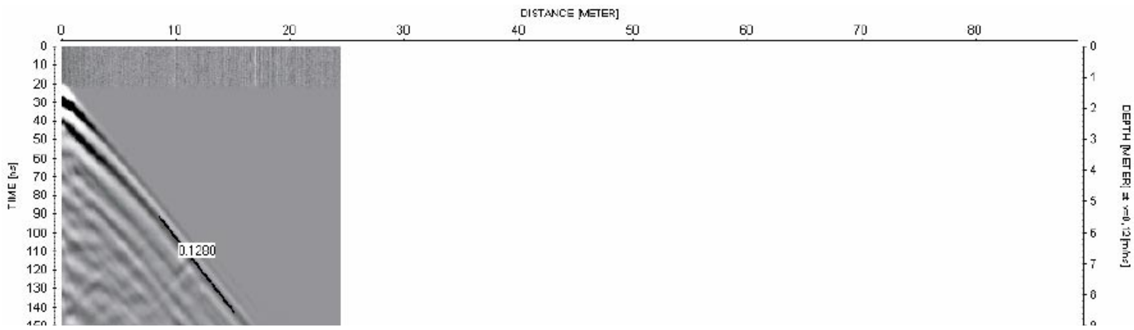


Figure 4-3. *Results from velocity measurements in HFM03 /1/.*

4.2.2 BIPS

The visualization of data is made with BDPP, a Windows based processing software for filtering, presentation and analysis of BIPS data. As no fracture mapping of the BIPS image is performed, the raw data was delivered on a CD-ROM together with printable pictures in *.pdf format before the field crew left the investigation site.

The printed results were delivered with measured length, together with adjusted length according to the length marks made on the cable when logging core-drilled boreholes (where the length marks are visible in the BIPS image). For printing of the BIPS images the printing software BIPP from RaaX was used.

4.3 Nonconformities

No nonconformities during the logging activity.

5 Results

The results from the BIPS measurements in KFM06B were delivered as raw data (*.bip-files) together with printable BIPS pictures in *.pdf format before the field crew left the investigation site. The information of the measurements was registered in SICADA, and the CD-ROM:s stored by SKB.

The RAMAC radar data for KFM06B was delivered as raw data (file format *.rd3 or *.rd5) with corresponding information files (file format *.rad) on CD-ROM:s to SKB before the field crew left the investigation site, whereas the data processing steps and results are presented in this report. Relevant information, including the interpretation presented in this report, was inserted into the SKB database SICADA.

5.1 RAMAC logging

The results of the interpretation of the radar measurements are presented in Tables 5-1 to 5-3. Radar data is also visualized in Appendix 1. It should be remembered that the images in Appendix 1 is only a composite picture of all events 360 degrees around the borehole, and do not reflect the orientation of the structures.

Only the larger clearly visible structures are interpreted in RadinterSKB. A number of minor structures or other also exist. It should also be pointed out that reflections interpreted will always get an intersection point with the borehole, but being located further away, they may in some cases not reach the borehole. Also almost parallel structures can be identified, especially in the 20 MHz data.

The data quality from KFM06B, (as seen in Appendix 1) is relatively satisfying, but in some parts of lower quality due to more conductive conditions. A conductive environment makes the radar wave to attenuate, which decreases the penetration. This is for instance seen very clearly in the 250 MHz data from 54 m depth. This conductive environment of course also reduces the possibility to distinguish and interpret possibly structures in the rock which otherwise could give a reflection.

As also seen in Appendix 1 the resolution and penetration of radar waves depend on the antenna frequency used. Low antenna frequency gives less resolution but higher penetration rate compared to a higher frequency. If structures can be identified with all three antenna frequencies, it can probably be explained by that the structure is quite significant.

In Table 5-1 below, the distribution of identified structures along the boreholes KFM06B is showed.

Table 5-2 summarises the interpretation of radar data from KFM06B. In the table the depth and intersection angle to the identified structures are listed. As seen some radar reflectors are marked with ±, which indicates an uncertainty in the interpretation of direction. The direction can in these cases be ±180 degrees. The direction to the object (the plane) is defined in Figure 5-1. This direction and the intersection angle are also given as strike and dip.

Observe that structure 13 is most likely due to a fixation of the borehole wall.

Table 5-1. Identified structures as a function of depth in KFM06B.

Depth (m)	No of structures
0–10	1
10–20	5
20–30	2
30–40	2
40–50	3
50–60	2
60–70	4
70–80	1
80–90	2
90–100	2
100–	3

Table 5-2. Interpretation of radar reflectors from dipole antennas 20, 100 and 250 MHz and the directional antenna in borehole KFM06B.

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas and Directional antenna)							
Site:		Forsmark					
Borehole name:		KFM06B					
Nominal velocity (m/μs):		128.0					
Name	Intersection depth	Inter-section angle	Object direction	Dip 1	Strike 1	Dip 2	Strike 2
1	8.7	65	6±	30	148	19	326
24	13.2	69					
23	15.0	74					
5	17.4	77					
2	17.7	39					
3	19.9	64					
4	21.8	63					
26	26.5	24					
6	35.2	73					
7	36.6	41					
9	44.3	84					
10	46.0	75	9±	25	147	13	321
12	47.3	74					
8	53.6	23	30	70	125		
13	55.6	80	99	9	96		
14	60.0	67					
25	68.5	63	342	33	305		
15	68.6	50					
21	68.6	25					
17	77.5	60					
18	86.1	51	3	49	151		
19	88.0	44					

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas and Directional antenna)							
Site:		**Forsmark**					
Borehole name:		**KFM06B**					
Nominal velocity (m/μs):		**128.0**					
Name	**Intersection depth**	**Inter-section angle**	**Object direction**	**Dip 1**	**Strike 1**	**Dip 2**	**Strike 2**
20	90.2	43					
16	94.8	12	207	72	306		
22	102.7	48					
28	112.0	50	177	34	337		
27	174.4	21					

In Appendix 1, the amplitude of the first arrival is plotted against the depth, for the 250 MHz dipole antennas. The amplitude variation along the borehole indicates changes of the electrical conductivity of the volume of rock surrounding the borehole. A decrease in this amplitude may indicate fracture zones, clay or rock volumes with increases in water content, i.e. increases in electric conductivity. The decrease in amplitude is shown in Table 5-3.

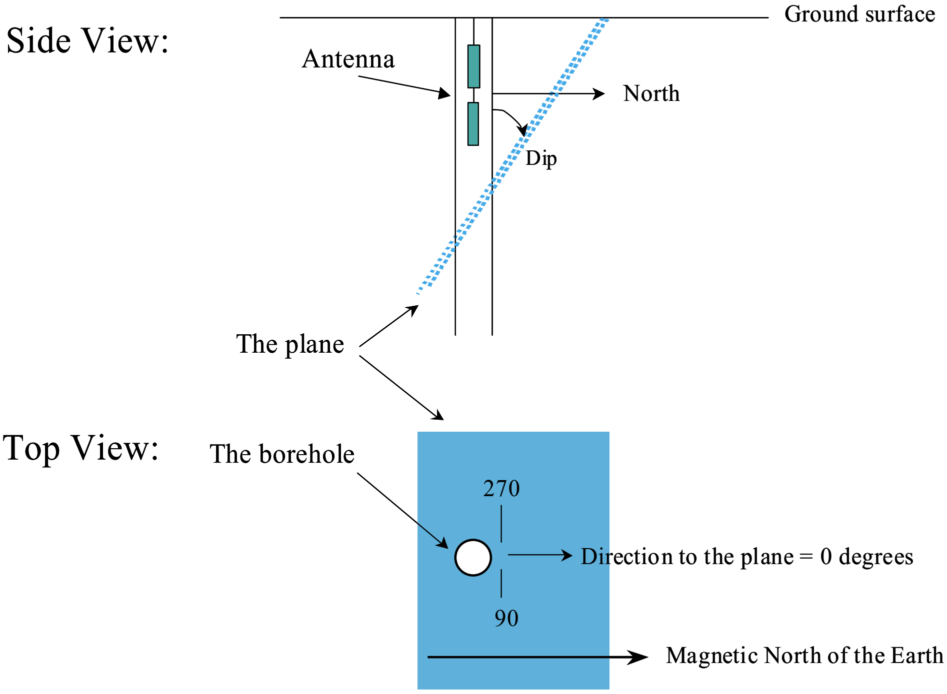


Figure 5-1. *Definition of direction to object as presented in Table 5-2.*

Table 5-3. Borehole length intervals in KFM06B with decreased amplitude for the 250 MHz antenna.

Length interval (m)
54–58
65–72
75–82
88–94

5.2 BIPS logging

The BIPS pictures are presented in Appendix 2.

There is no marks created by the drill rig in this borehole. Therefore the length adjustment for the BIPS measurement is done from the empirical knowledge of the tension and other depth related error.

In order to control the quality of the system, calibration measurements were performed in a test pipe before logging the first borehole and after logging of the last borehole. The resulting images displayed no difference regarding the colours and focus of the images. Results of the test loggings were included in the delivery of the field data and are also presented in Figure 4-2 in this report.

The logging in KFM06B has been performed in two runs. The first run 2004-06-17 ended up in a jammed probe at 56 m. The rescue operation two weeks after was successful and the probe was retrieved safely back with limited damage on the logging cable. The first run was performed with a BIPS 4 system owned by RAYCON. Figure 5-2 shows a section around 55 m just before the probe got jammed.

The image quality for the second run 2005-02-10 was excellent. The water is of perfect quality and it is no discolouring effects from the drilling phase along the borehole. To avoid more equipment to be jammed two perforated cylindrical steel plates was installed in the critical parts of the borehole. Figure 5-3 shows a 1.8 m section after mounting the steel plates.

In Appendix 2 the BIPS pictures refer to the second run of 2005-02-10.

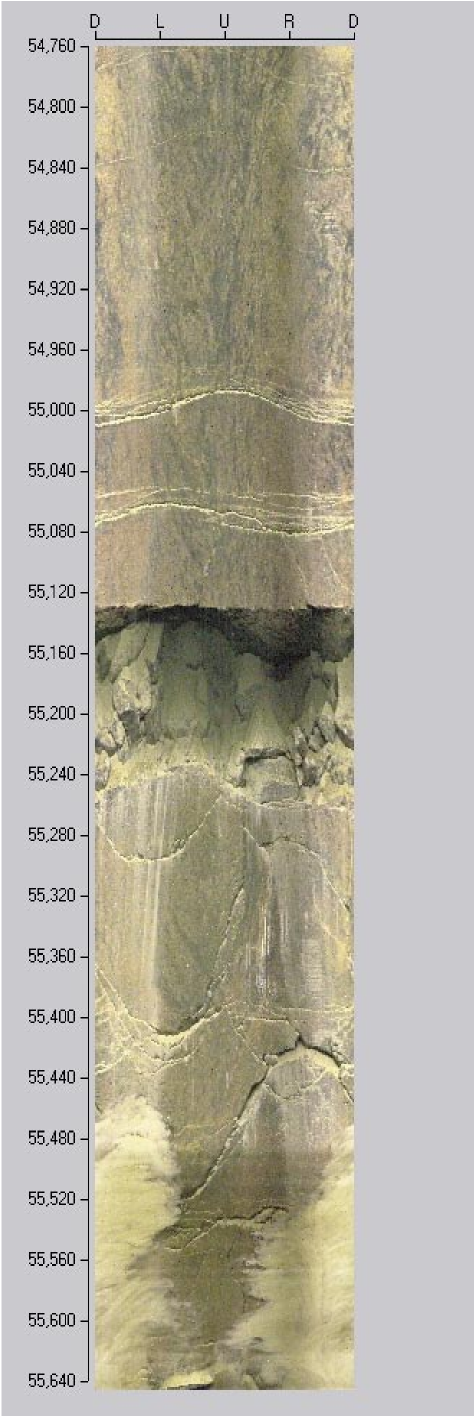


Figure 5-2*. A 88 cm section showing the upper part of the area with fractures, causing the probe to get jammed.*

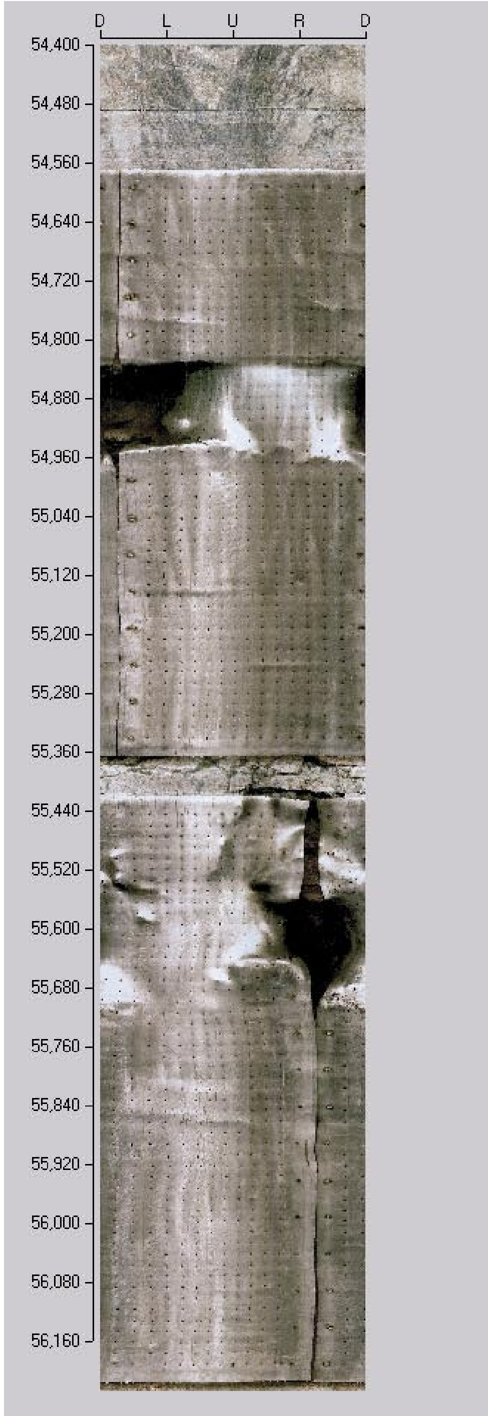
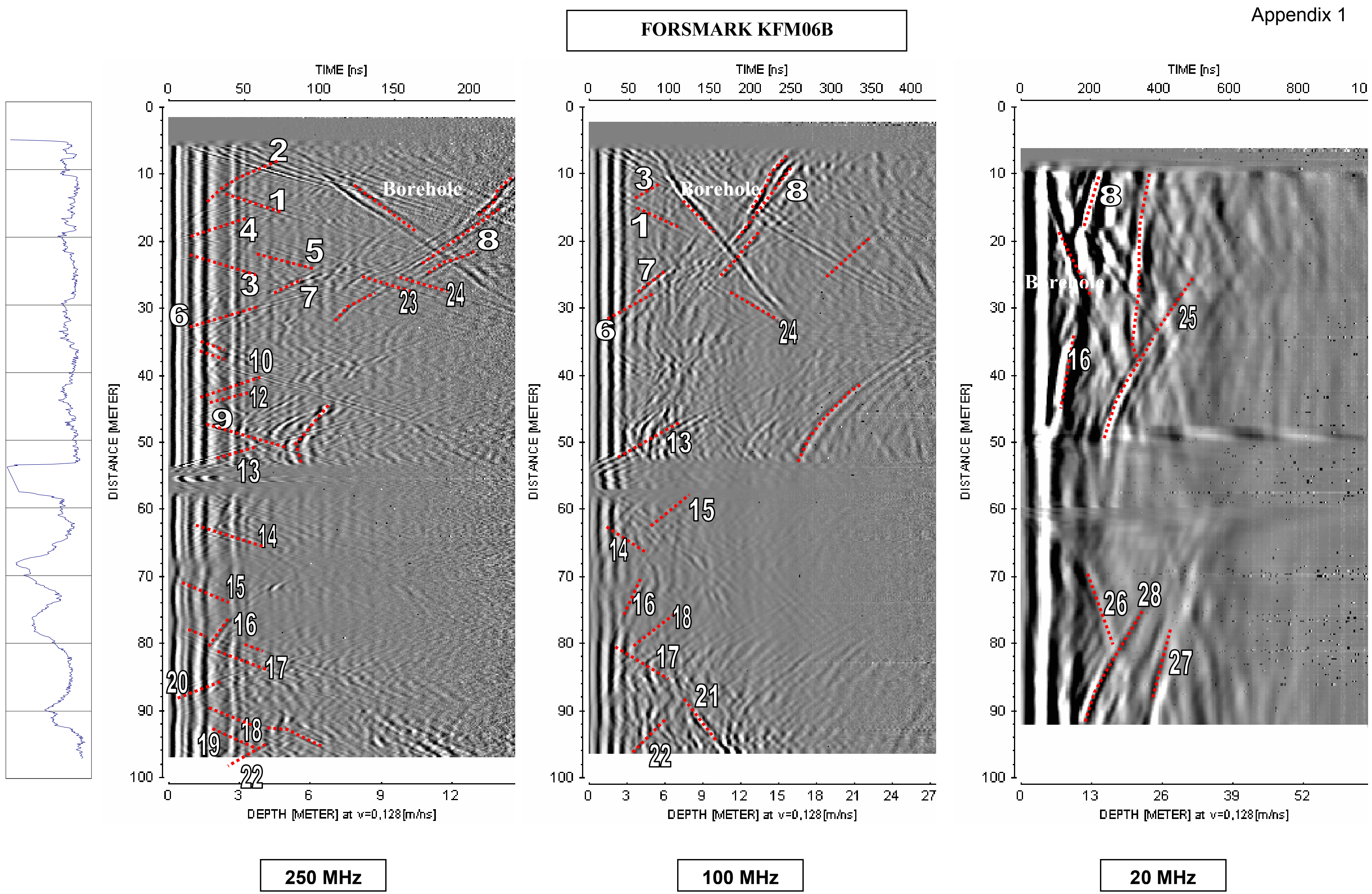


Figure 5-3*. A 1.8 m section showing the perforated steel plates. Observe the different length scales of Figure 5-2 and Figure 5-3.*

References

/1/ **Gustafsson C, Nilsson P, 2003.** Geophysical Radar and BIPS logging in borehole HFM01, HFM02, HFM03 and the percussion drilled part of KFM01A. SKB P-03-39. Svensk Kärnbränslehantering AB.

Radar logging in KFM06B, 0 to 95 m, dipole antennas 250, 100 and 20 MHz



Appendix 2

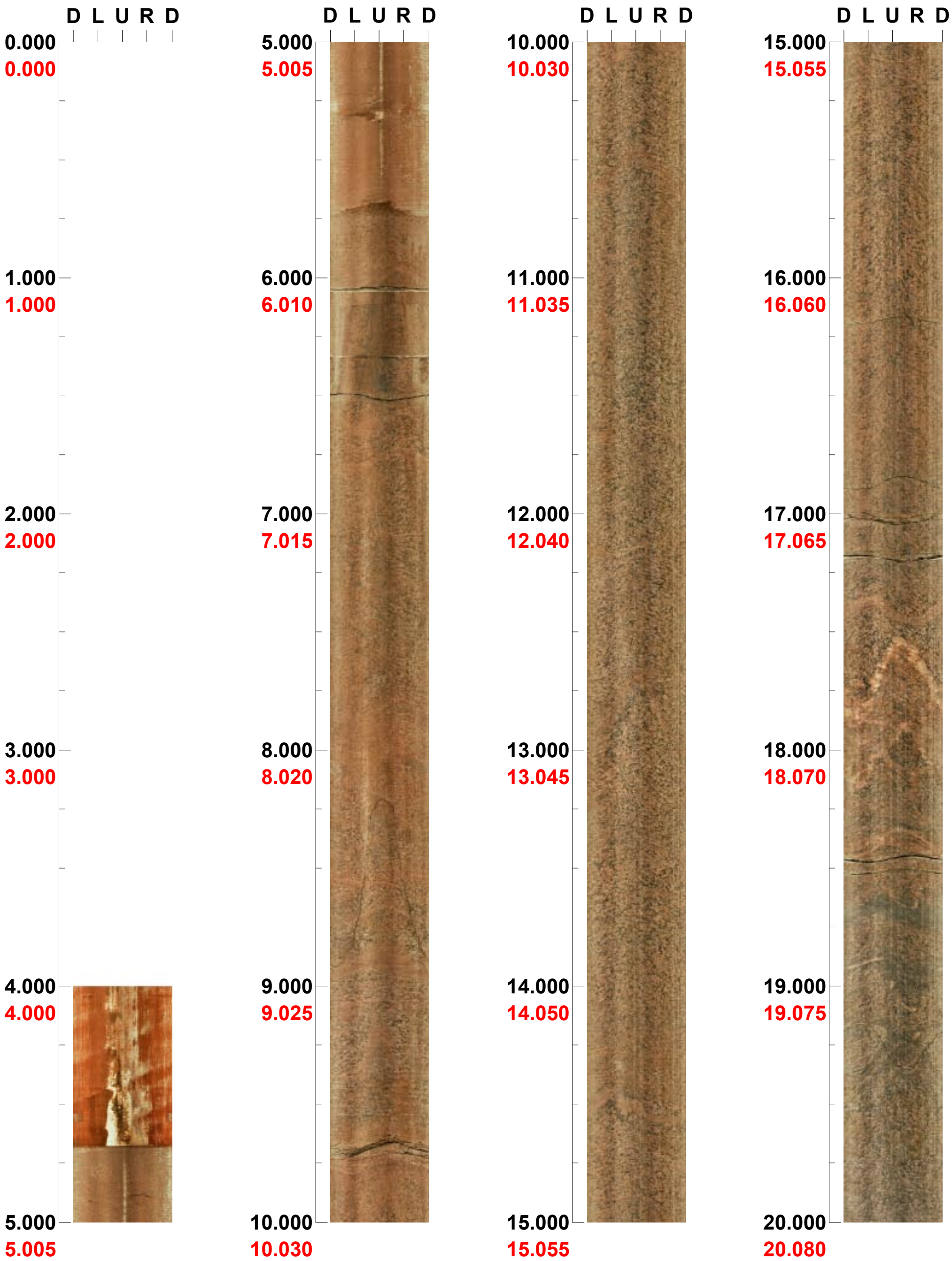
BIPS logging in KFM06B, 4 to 97 m

Project name: Forsmark

Image file	: c:\work\r5282s~1\kfm06b\bips\05-02-10\kfm06b.bip
BDT file	: c:\work\r5282s~1\kfm06b\bips\05-02-10\kfm06b.bdt
Locality	: FORSMARK
Bore hole number	: KFM06B
Date	: 05/02/10
Time	: 16:05:00
Depth range	: 4.000 - 97.481 m
Azimuth	: 300
Inclination	: -85
Diameter	: 76.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 175 %
Pages	: 5
Color	: +0 +0 +0

Appendix 2 **Project name: Forsmark**
Bore hole No.: KFM06B **Azimuth: 300** **Inclination: -85**

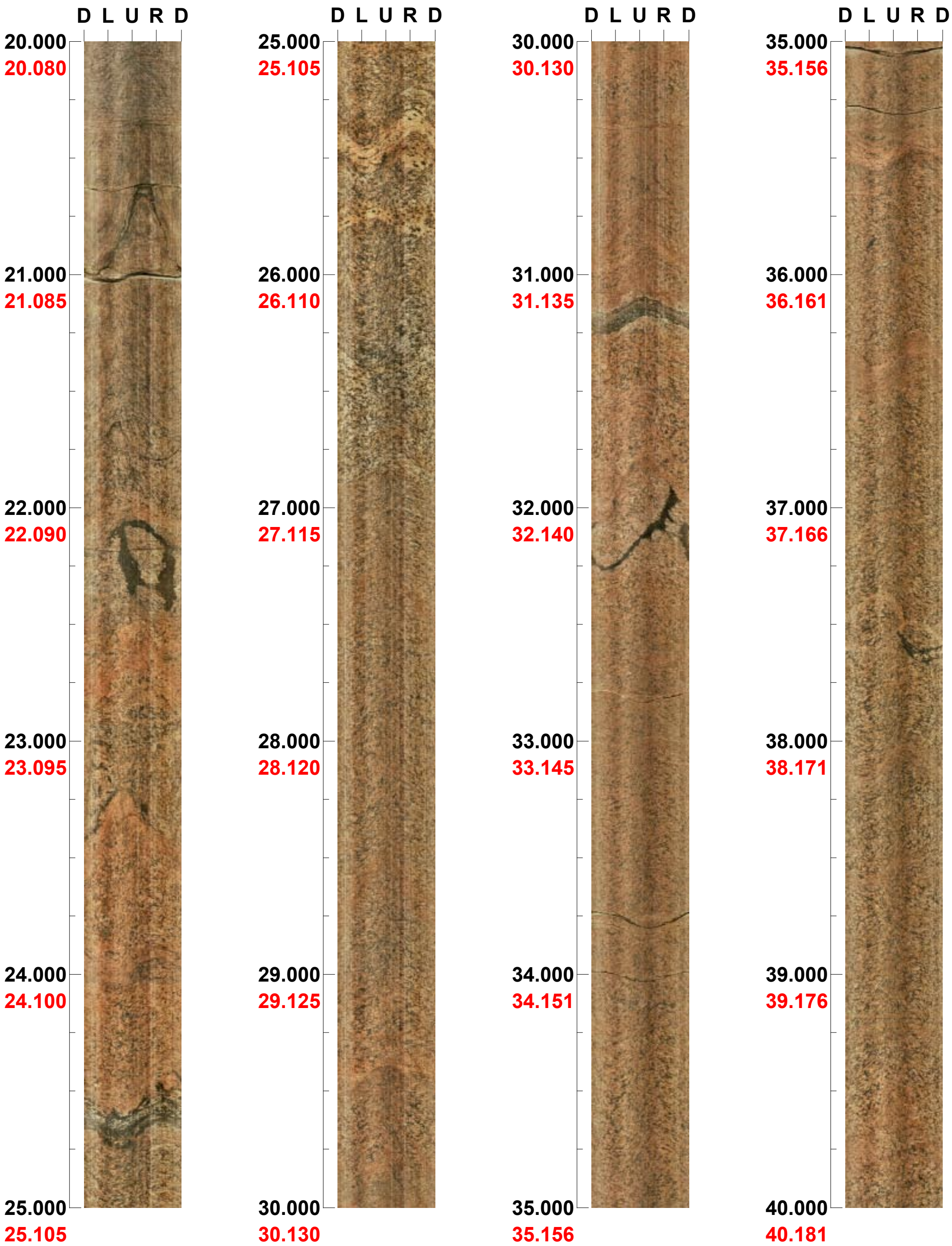
Depth range: 0.000 - 20.000 m



(1 / 5) **Scale: 1/25** **Aspect ratio: 175 %**

Appendix 2 **Project name: Forsmark**
Bore hole No.: KFM06B **Azimuth: 300** **Inclination: -85**

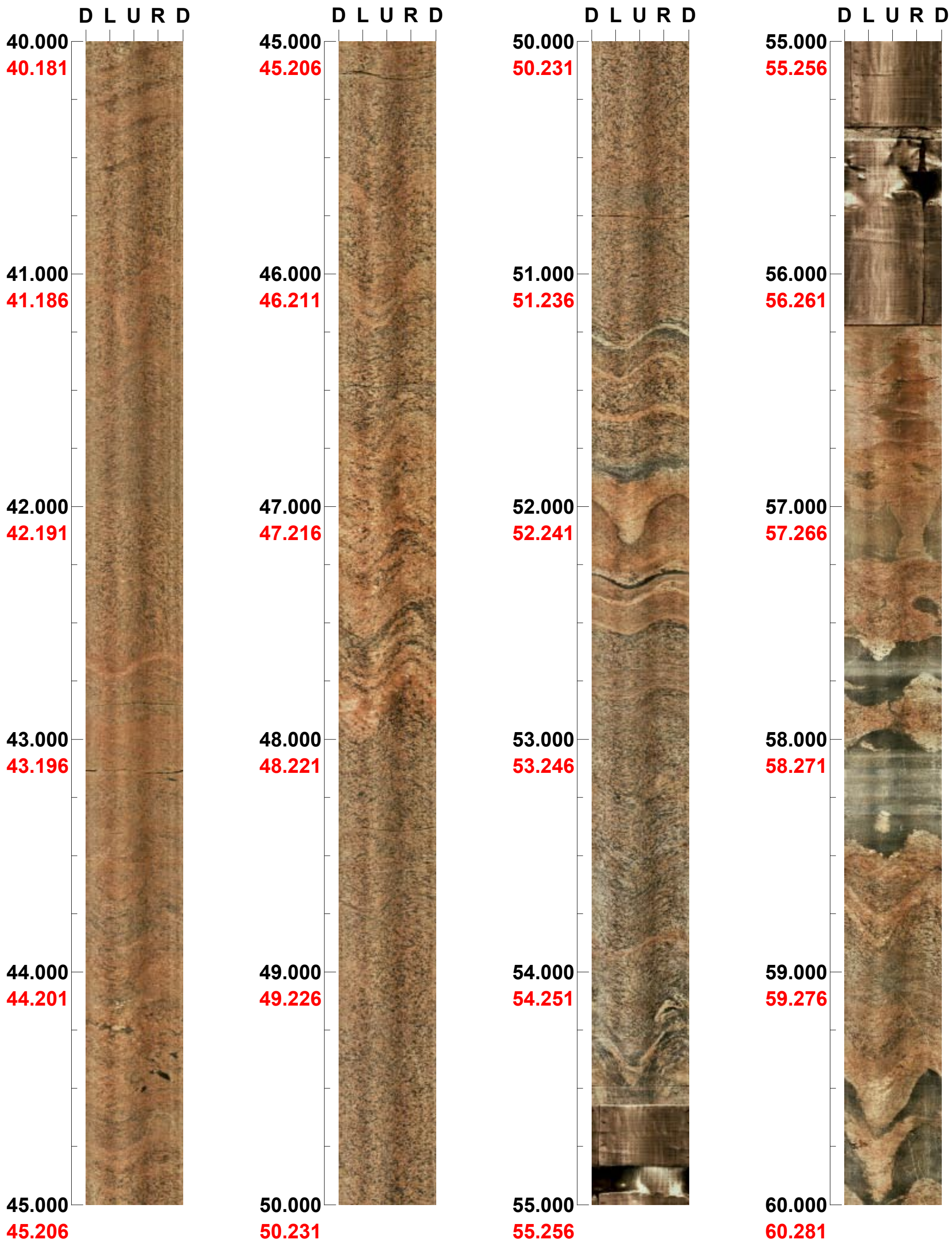
Depth range: 20.000 - 40.000 m



(2 / 5) **Scale: 1/25** **Aspect ratio: 175 %**

Appendix 2 **Project name: Forsmark**
Bore hole No.: KFM06B **Azimuth: 300** **Inclination: -85**

Depth range: 40.000 - 60.000 m

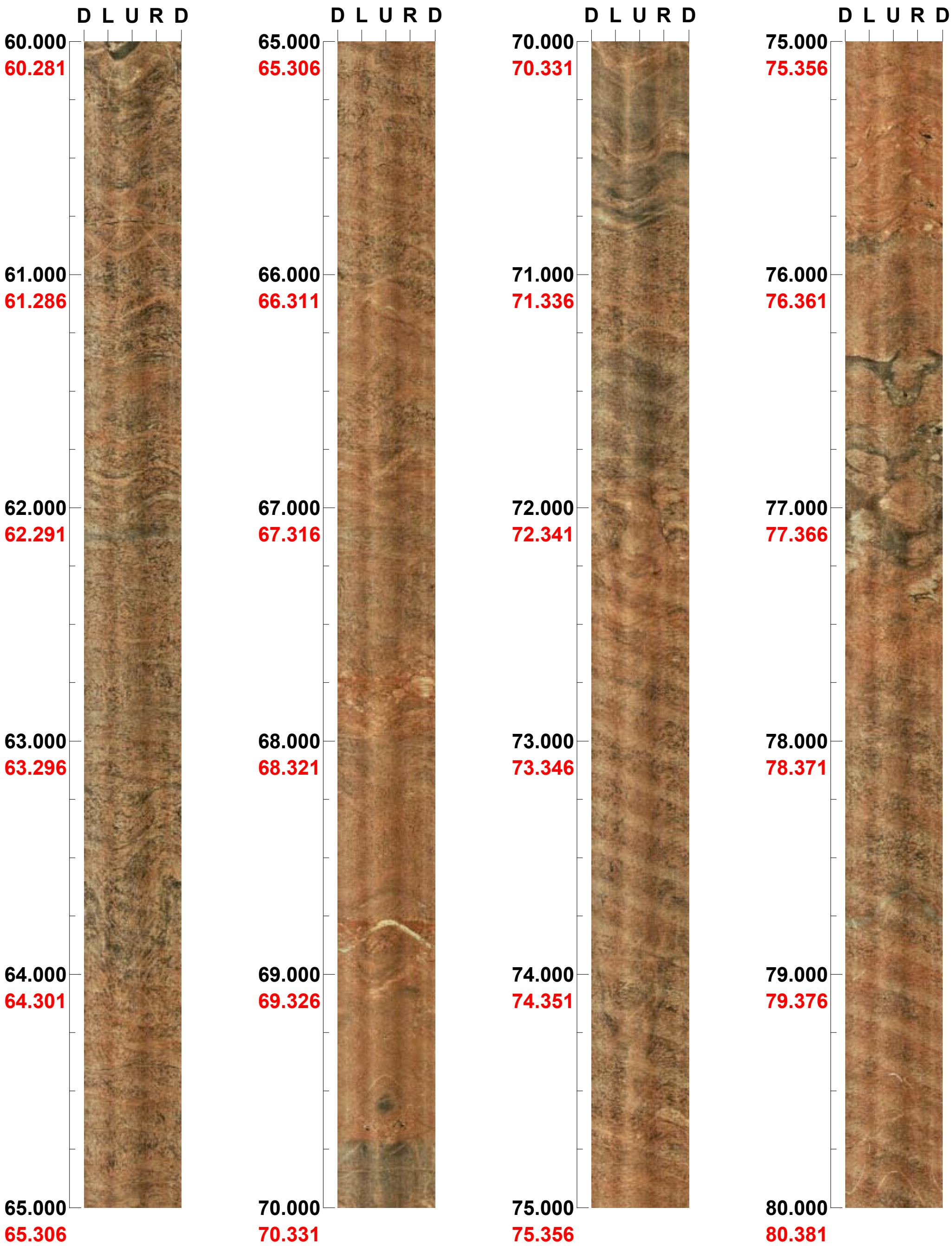


(3 / 5) **Scale: 1/25** **Aspect ratio: 175 %**

Appendix 2 **Project name: Forsmark**

Bore hole No.: KFM06B **Azimuth: 300** **Inclination: -85**

Depth range: 60.000 - 80.000 m



(4 / 5) **Scale: 1/25** **Aspect ratio: 175 %**

Appendix 2 **Project name: Forsmark**
Bore hole No.: KFM06B **Azimuth: 300** **Inclination: -85**

Depth range: 80.000 - 97.481 m

(5 / 5) **Scale: 1/25** **Aspect ratio: 175 %**