P-04-69

Forsmark Site Investigation

RAMAC and BIPS logging in borehole KFM06A, HFM16, HFM17, HFM18 and HFM19

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April 2004

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Contents

1 Introduction

This document reports data gained during geophysical logging, which is one of the activities performed within the site investigation at Forsmark. The logging operations presented here include borehole radar (RAMAC) and TV-logging (BIPS) and were carried out in the percussion drilled part of borehole KFM06A and the percussion drilled boreholes HFM16, HFM17, HFM18 and HFM19, see Table 1-1 and Figure 1-1.

Table 1-1. Investigated boreholes.

Borehole ID	Azimuth (degrees from north)	Inclination (degrees from horizontal)	Length (m)	Investigated section (m)
KFM06A	301	60	100	0–100
HFM16	328	84	133	0–130
HFM17	319	84	211	0–200
HFM18	313	59	181	0–180
HFM19	281	58	185	0–180

The borehole radar measurements and BIPS measurements were conducted by Malå Geoscience AB / RAYCON during December 2003 and January 2004, according to activity plan AP PF 400-03-87 (SKB internal controlling document).

The applied investigation techniques comprised:

- Borehole radar with dipole radar antennas.
- Borehole TV logging with the so-called BIP-system (Borehole Image Processing System), which is a high resolution, side viewing, colour borehole TV system.

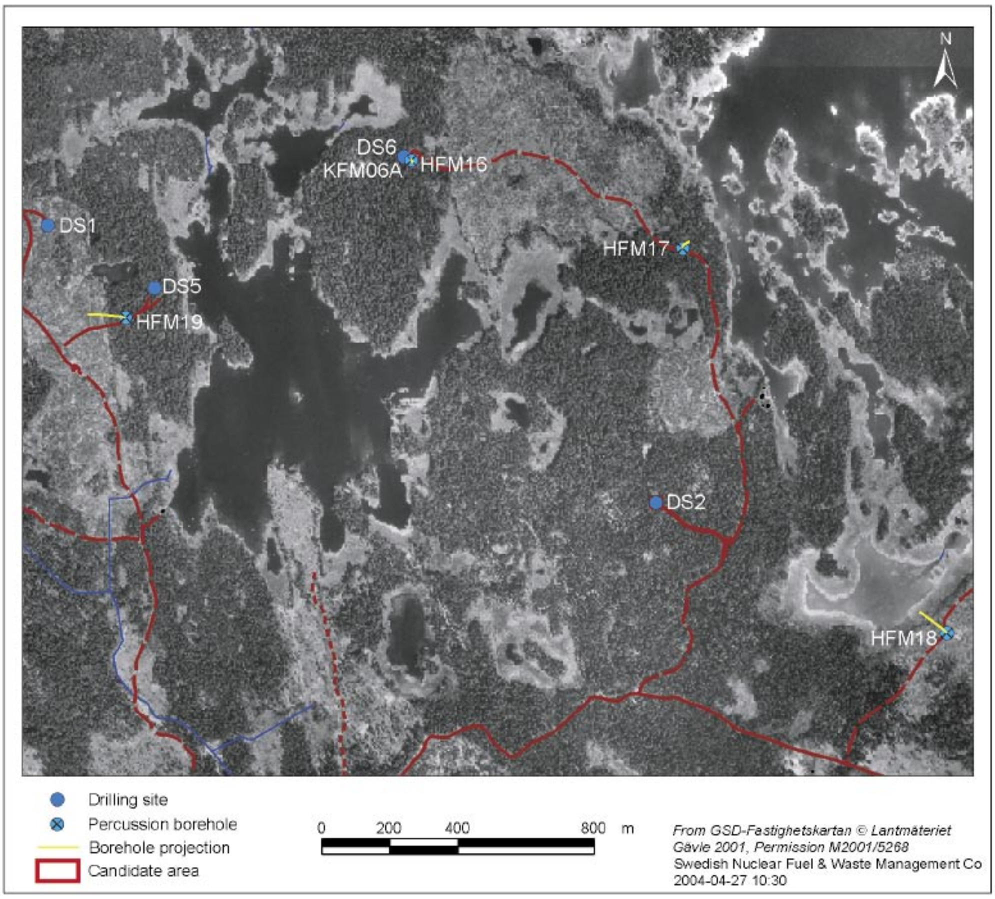


***Figure 1-1.** Location of the investigated boreholes KFM06A, HFM16, HFM17, HFM18 and HFM19 in the Forsmark area.*

2 Objective and scope

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

This report describes the equipment used as well the measurement procedures and data gained.

3 Equipment

3.1 RAMAC

The RAMAC GPR system owned by SKB is fully digital, and emphasis has been laid on high survey speed and smooth field operation. The system operates dipole and directional antennas (see Figure 3-1). A system description is given in the method description "Metodbeskrivning för borrhålsradar" (SKB MD 252.020, Version 1.0).

The borehole radar system consists of a transmitter and a receiver. During operation, an electromagnetic pulse, within the frequency range 20 to 250 MHz, is emitted and penetrates the bedrock. The resolution and penetration of the radar waves depend on the antenna frequency used. A low antenna frequency results in lower resolution but higher penetration rate compared to a higher frequency. If a feature, e.g. a water-filled fracture, with anomalous electrical properties compared to the surrounding is encountered, the pulse is reflected back to the receiver and recorded.

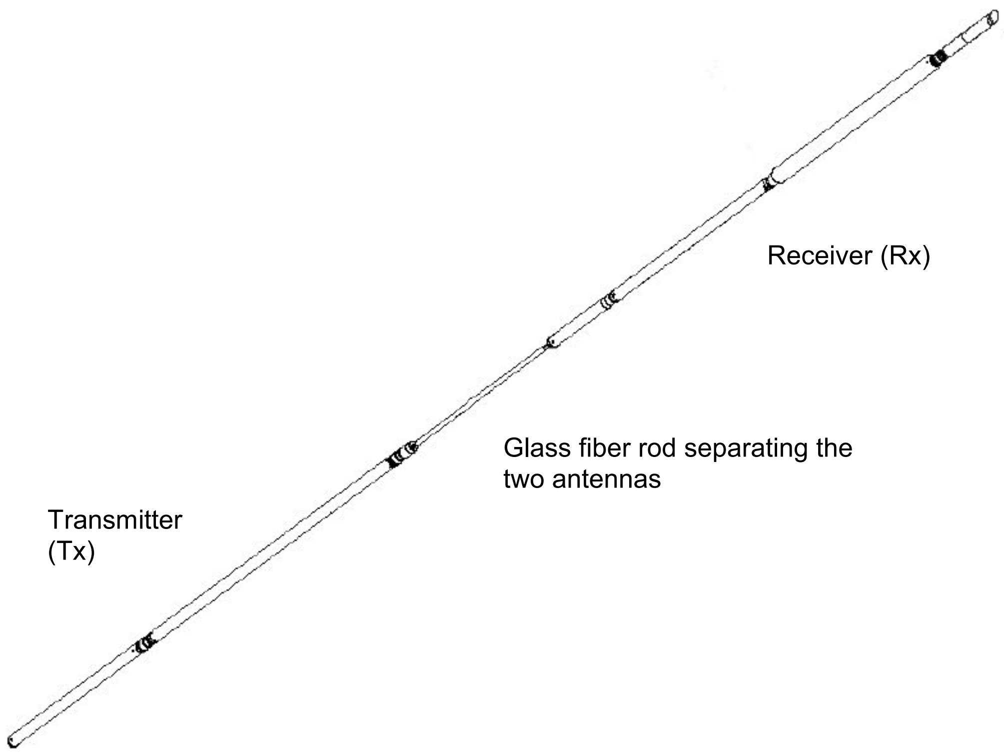


Figure 3-1. *Example of a borehole antenna.*

3.2 TV-Camera – BIPS

The BIPS 1500 system used is owned by SKB and described in the method description "Metodbeskrivning för TV-loggning med BIPS" (SKB MD 222.006, Version 1.0). 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, pixel circles are grabbed with a resolution of 360 pixels/circle.

The BIPS images can be orientated by means of to two alternative methods, either with a compass (vertical and sub-vertical boreholes) or with a gravity sensor (inclined boreholes).

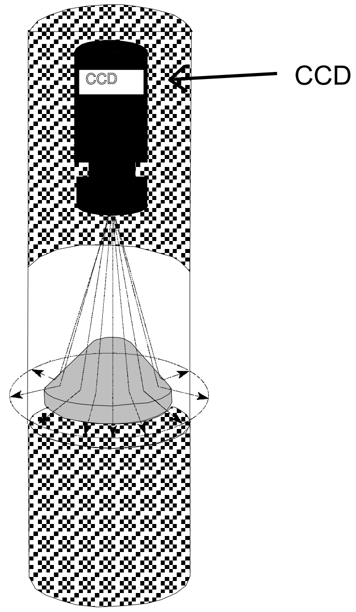


Figure 3-2. *The BIP-system. Illustration of the conical mirror scanning.*

4 Execution

4.1 Data aquisition

RAMAC

For the borehole radar measurements, dipole antennas were engaged. The dipole antennas used have central frequencies of 20 MHz, 100 MHz and 250 MHz respectively.

During logging, the dipole antennas (transmitter and receiver) are lowered continuously into the borehole and the data recorded on a field PC. The antennas are kept at a fixed separation by glass fibre rods according to Table 4-1 to 4-3. See also Figure 3-1 and 4-1.

For detailed information see the SKB MD 252.020 for method description and MD 600.004 (“Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning”) for cleaning of equipment.

Information on the system settings for the different antennas used in the investigation of KFM06A, HFM16, HFM17, HFM18 and HFM19 is presented in Table 4-1 to 4-5 below.

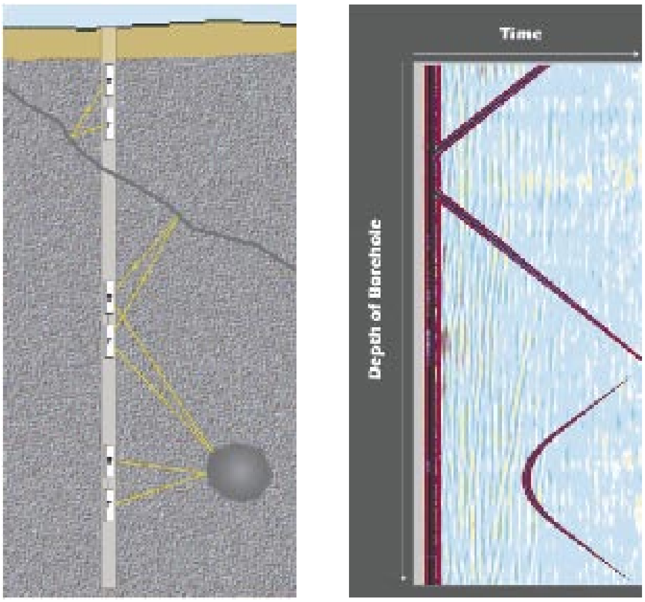


Figure 4-1. *The principle of radar borehole reflection survey (left) and a resulting radargram (right).*

Table 4-1. Radar logging information from KFM06A.

Site:	**Forsmark**	**Logging company:**		**RAYCON**
BH:	**KFM06A**	**Equipment:**		**SKB RAMAC**
Type:	**Dipole**	**Manufacturer:**		**MALÅ GeoScience**
Operators:	**CG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
	Logging date:	03-12-03	03-12-03	03-12-03
	Reference:	T.O.C.	T.O.C.	T.O.C.
	Sampling frequency (MHz):	2588	951	257
	Number of samples:	619	518	518
	Number of stacks:	Auto	Auto	Auto
	Signal position:	–0.32	–0.32	–1.43
	Logging from (m):	1.5	2.6	6.25
	Logging to (m):	98.3	96.9	89.8
	Trace interval (m):	0.1	0.2	0.25
	Antenna separation (m):	2.4	3.9	10.05

Table 4-2. Radar logging information from HFM16.

Site:	**Forsmark**	**Logging company:**		**RAYCON**
BH:	**HFM16**	**Equipment:**		**SKB RAMAC**
Type:	**Dipole**	**Manufacturer:**		**MALÅ GeoScience**
Operators:	**CG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
	Logging date:	03-12-04	03-12-04	03-12-04
	Reference:	T.O.C.	T.O.C.	T.O.C.
	Sampling frequency (MHz):	2588	951	257
	Number of samples:	619	518	518
	Number of stacks:	Auto	Auto	Auto
	Signal position:	–0.32	–0.32	–1.43
	Logging from (m):	1.5	2.6	6.25
	Logging to (m):	127.9	126.8	123.0
	Trace interval (m):	0.1	0.2	0.25
	Antenna separation (m):	2.4	3.9	10.05

Table 4-3. Radar logging information from HFM17.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**HFM17**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Operators:	**CG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
	Logging date:	04-01-15	04-01-15	04-01-15
	Reference:	T.O.C.	T.O.C.	T.O.C.
	Sampling frequency (MHz):	2588	951	257
	Number of samples:	619	518	518
	Number of stacks:	Auto	Auto	Auto
	Signal position:	–0.32	–0.32	–1.43
	Logging from (m):	1.5	2.6	6.25
	Logging to (m):	208	206.9	202.8
	Trace interval (m):	0.1	0.2	0.25
	Antenna separation (m):	2.4	3.9	10.05

Table 4-4. Radar logging information from HFM18.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**HFM18**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Operators:	**CG / JG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
	Logging date:	04-01-15	04-01-15	04-01-15
	Reference:	T.O.C.	T.O.C.	T.O.C.
	Sampling frequency (MHz):	2588	951	257
	Number of samples:	619	518	518
	Number of stacks:	Auto	Auto	Auto
	Signal position:	–0.32	–0.32	–1.43
	Logging from (m):	1.5	2.6	6.25
	Logging to (m):	177.6	177.9	173.9
	Trace interval (m):	0.1	0.2	0.25
	Antenna separation (m):	2.4	3.9	10.05

Table 4-5. Radar logging information from HFM19.

Site:	**Forsmark**	**Logging company:**		**RAYCON**
BH:	**HFM19**	**Equipment:**		**SKB RAMAC**
Type:	**Dipole**	**Manufacturer:**		**MALÅ GeoScience**
Operators:	**CG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
	Logging date:	04-01-16	04-01-16	04-01-16
	Reference:	T.O.C.	T.O.C.	T.O.C.
	Sampling frequency (MHz):	2588	951	257
	Number of samples:	619	518	518
	Number of stacks:	Auto	Auto	Auto
	Signal position:	–0.32	–0.32	–1.43
	Logging from (m):	1.5	2.6	6.25
	Logging to (m):	183.2	182.7	178.6
	Trace interval (m):	0.1	0.2	0.25
	Antenna separation (m):	2.4	3.9	10.05

BIPS

For detailed information on BIPS measurements see the SKB MD 222.006 for a method description and MD 600.004 for cleaning of equipment.

During the measurements, pixel circles with a resolution of 360 pixels/circle were recorded 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.

A gravity sensor was used for the orientation of the BIPS camera.

Depth measurements

The depth recording for the RAMAC and BIPS systems is taken care of by a measuring wheel mounted on the cable winch. In core drilled boreholes, there are reference marks at approximately every 50 m. When the BIPS logging is made, the logging cable is marked with a piece of scotch tape for every single depth mark. These marks are then used for controlling the depth of the RAMAC logging. The same marks are used to controll both BIPS and RAMAC loggings in percussion drilled boreholes.

The experience from measurements in cored boreholes in Forsmark and Oskarshamn is that the depth divergence is less than 50 cm in the deepest parts of the deep (c 1000 m) boreholes. The boreholes discussed in this report are less than 200 m deep and the divergence is assumed to be very limited.

4.2 Analyses and interpretation

Radar

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

The data presented in this report is related to the "measurement point", which is defined to be the central point between the transmitter and the receiver antenna.

In the reflection mode, borehole radar primarily offer a high-resolution image of the rock mass, visualizing the geometry of plane structures (contacts between rock units of different lithology, thin marker beds, fractures, fracture zones etc), which may or may not intersect the borehole, or showing the presence of local features (cavities, lenses etc) around the borehole.

In the reflection mode, borehole radar primarily offer a high-resolution image of the rock mass, visualizing the geometry of plane structures (contacts between rock units of different lithology, thin marker beds, fractures, fracture zones etc), which may or may not intersect the borehole, or showing the presence of local features (cavities, lenses etc) around the borehole.

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 consistent in the rock volume investigated.

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 a borehole at drill site No 1 (the percussion drilled borehole HFM03) while moving the receiver downwards in the borehole. The result is plotted in Figure 4-2. The calculation shows a velocity of 128 m/micro second. The velocity measurement was performed with the 100 MHz antenna /1/.

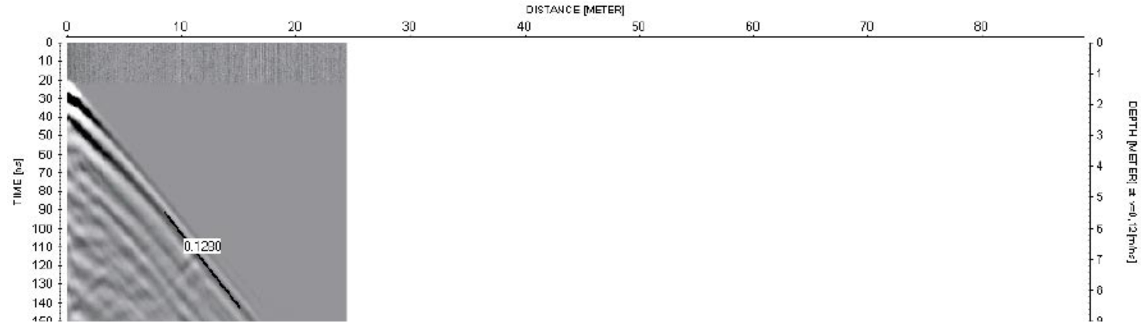


Figure 4-2. Results from velocity measurements in HFM03 /1/.

The visualization of data in Appendix 1 to 5 is made with REFLEX, a Windows based processing software for filtering and analysis of radar data. The processing steps are shown in Table 4-6 to 4-10.

For the interpretation of the intersection angle between the borehole axis and the planes visible on the radargrams, the RadinterSKB software has been used. The interpreted intersection points and intersection angles of the detected structures are presented in Table 5-1 to 5-5 and also visible on the radargrams in Appendix 1 to 5.

Table 4-6. Processing steps for borehole radar data from KFM06A.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**KFM06A**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
	Processing:	DC removal	DC removal	DC removal
		Move start time	Move start time	Move start time
		Gain	Gain	Gain

Table 4-7. Processing steps for borehole radar data from HFM16.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**HFM16**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
	Processing:	DC removal	DC removal	DC removal
		Move start time	Move start time	Move start time
		Gain	Gain	Gain

Table 4-8. Processing steps for borehole radar data from HFM17.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**HFM17**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
	Processing:	DC removal	DC removal	DC removal
		Move start time	Move start time	Move start time
		Gain	Gain	Gain

Table 4-9. Processing steps for borehole radar data from HFM18.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**HFM18**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
	Processing:	DC removal	DC removal	DC removal
		Move start time	Move start time	Move start time
		Gain	Gain	Gain

Table 4-10. Processing steps for borehole radar data from HFM19.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**HFM19**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
	Processing:	DC removal	DC removal	DC removal
		Move start time	Move start time	Move start time
		Gain	Gain	Gain

BIPS

The visualization of data (see Appendix 6 to 10) is made with BDPP, a Windows based processing software for filtering, presentation and analyzing of BIPS data. No fracture mapping based on the BIPS images has been performed.

5 Results and data delivery

The results from the radar and BIPS measurements were delivered as raw data (*.bip-files) on CD-ROMs to SKB together with printable BIPS pictures in *.pdf format before the field crew left the investigation site. The information on the measurements is registered in SICADA and the VHS-tapes, MO-disks and CD-ROMs are stored by SKB.

RAMAC radar data has been delivered as raw data (fileformat *.rd3 or *.rd5) with corresponding information files (file format *.rad), whereas the data processing steps and results are presented in this report. Relevant information, including the interpretation presented in this report, has been inserted into the SKB database SICADA.

The SICADA reference to the BIPS and RAMAC logging activities in KFM06A, HFM16, HFM17, HFM18 and HFM19 is Field note Forsmark no 217 (KFM06A and HFM16) and no 235 (HFM17–19).

5.1 RAMAC logging

The results of the interpretation of the radar measurements are presented in Table 5-1 to 5-10. Radar data is also visualized in Appendix 1 to 5. It should be remembered that the images in Appendix 1 to 5 are only composite pictures of all events, 360 degrees around the borehole, and do not reflect the true orientation of the structures.

Only the major, clearly visible structures are interpreted in RadinterSKB. A number of minor structures were encountered as well as indicated in Appendix 1 to 5.

The data quality, as seen in Appendix 1 to 5, is relatively satisfying. However, the measurements in parts of the boreholes suffer from deteriorated quality due to increased electrical conductivity in the rock or borehole fluid. A conductive environment entails attenuation of the radar waves, resulting in decreased penetration. This is most evident as regards the 250 MHz data from HFM17 and HFM19 (Appendix 3 and 5), where the radar signal is almost completely attenuated, most probably due to high electric borehole fluid conductivity. The conductive environment decreases the possibility to map the structures in the boreholes.

As also seen in Appendix 1 to 5, the resolution and penetration of the radar waves depend of the antenna frequency used. A high frequency will result in a high resolution but a lower penetration rate compared to a lower frequency.

Table 5-1. Identified structures as a function of depth in KFM06A.

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

Table 5-2. Identified structures as a function of depth in HFM16.

Depth (m)	No of structures
– 10	2
10 – 20	–
20 – 30	1
30 – 40	1
40 – 50	1
50 – 60	2
60 – 70	2
70 – 80	1
80 – 90	3
90 – 100	2
100 –110	2
110 – 120	1
120 – 130	1
130 – 140	–
140 – 150	–
150 –	2

Table 5-3. Identified structures as a function of depth in HFM17.

Depth (m)	No of structures
– 10	1
10 – 20	1
20 – 30	1
30 – 40	1
40 – 50	2
50 – 60	–
60 – 70	–
70 – 80	1
80 – 90	–
90 – 100	2
100 –110	–
110 – 120	1
120 – 130	1
130 – 140	1
140 – 150	1
150 –	2

Table 5-4. Identified structures as a function of depth in HFM18.

Depth (m)	No of structures
– 10	1
10 – 20	–
20 – 30	1
30 – 40	3
40 – 50	1
50 – 60	–
60 – 70	1
70 – 80	1
80 – 90	–
90 – 100	1
100 –110	1
110 – 120	2
120 – 130	4
130 – 140	1
140 – 150	1
150 –	5

Table 5-5. Identified structures as a function of depth in HFM19.

Depth (m)	No of structures
– 10	2
10 – 20	1
20 – 30	1
30 – 40	3
40 – 50	1
50 – 60	–
60 – 70	1
70 – 80	1
80 – 90	1
90 – 100	–
100 –110	3
110 – 120	–
120 – 130	2
130 – 140	2
140 – 150	1
150 –	5

Table 5-6 and 5-10 summarise the interpretation of radar data from KFM06A, HFM16, HFM17, HFM18 and HFM19. Many structures can be identified in the data from more than one antenna frequency.

Table 5-6. Model information from dipole antennas 20, 100 and 250 MHz, KFM06A.

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas)			
Site:		**Forsmark**	
Borehole name:		**KFM06A**	
Nominal velocity (m/μs):		**128.00**	
Object type	**Name**	**Intersection depth**	**Intersection angle**
PLANE	B	23.2	39
PLANE	A	24.1	54
PLANE	C	39.3	41
PLANE	D	44.9	45
PLANE	G	50.4	74
PLANE	E	52.0	43
PLANE	F	56.6	46
PLANE	H	61.0	46
PLANE	I	69.1	45
PLANE	J	69.7	62
PLANE	K	72.8	46
PLANE	L	83.6	58
PLANE	M	86.5	78
PLANE	N	91.1	48
PLANE	O	93.7	71
PLANE	P	96.8	90
PLANE	Q	125.8	57
PLANE	R	168.0	20
PLANE	S	213.2	18

Names in table according to Appendix 1.

Table 5-7. Model information from dipole antennas 20, 100 and 250 MHz, HFM16.

RADINTER MODEL INFORMATION
(20, 100 and 250 MHz Dipole Antennas)

Site:	**Forsmark**
Borehole name:	**HFM16**
Nominal velocity (m/μs):	**128.00**

Object type	**Name**	**Intersection depth**	**Intersection angle**
PLANE	R	–117.9	5
PLANE	V	–69.7	11
PLANE	U	Visible at 20–30 m	0
PLANE	A	26.0	54
PLANE	B	35.8	68
PLANE	C	40.8	76
PLANE	D	57.1	61
PLANE	E	59.9	65
PLANE	F	68.2	51
PLANE	G	69.5	60
PLANE	H	71.3	51
PLANE	I	85.4	72
PLANE	J	88.8	47
PLANE	K	88.9	61
PLANE	L	90.6	31
PLANE	M	93.6	77
PLANE	N	103.3	65
PLANE	O	105.1	70
PLANE	P	119.5	61
PLANE	S	124.9	17
PLANE	Q	152.1	19
PLANE	T	341.4	7

Names in table according to Appendix 2.

Table 5-8. Model information from dipole antennas 20, 100 and 250 MHz, HFM17.

RADINTER MODEL INFORMATION
(20, 100 and 250 MHz Dipole Antennas)

Site: **Forsmark**
Borehole name: **HFM17**
Nominal velocity (m/μs): **128.00**

Object type	Name	Intersection depth	Intersection angle
PLANE	O	–86.0	10
PLANE	A	12.0	42
PLANE	B	27.8	32
PLANE	C	32.2	88
PLANE	D	46.8	29
PLANE	E	47.2	45
PLANE	F	70.4	42
PLANE	G	92.2	60
PLANE	H	98.5	64
PLANE	I	116.8	39
PLANE	J	121.7	61
PLANE	L	133.1	24
PLANE	M	146.7	59
PLANE	N	177.9	18
PLANE	K	210.1	4

Names in table according to Appendix 3.

Table 5-9. Model information from dipole antennas 20, 100 and 250 MHz, HFM18.

RADINTER MODEL INFORMATION
(20, 100 and 250 MHz Dipole Antennas)

Site:	**Forsmark**
Borehole name:	**HFM18**
Nominal velocity (m/μs):	**128.00**

Object type	Name	Intersection depth	Intersection angle
PLANE	WW	–190.9	6
PLANE	D	16.3	49
PLANE	A	30.8	56
PLANE	B	35.5	68
PLANE	C	38.8	73
PLANE	E	48.2	82
PLANE	F	65	80
PLANE	G	79.0	90
PLANE	H	96.8	70
PLANE	L	107.6	80
PLANE	I	111.3	26
PLANE	J	112.7	50
PLANE	M	121.6	78
PLANE	N	127.2	55
PLANE	O	128.1	90
PLANE	K	129.2	27
PLANE	P	131.5	72
PLANE	Q	146.4	73
PLANE	R	161.3	62
PLANE	S	171.3	62
PLANE	T	173.9	68
PLANE	U	177.2	71
PLANE	V	190.7	42

Names in table according to Appendix 4.

Table 5-10. Model information from dipole antennas 20, 100 and 250 MHz, HFM19.

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas)			
Site:		**Forsmark**	
Borehole name:		**HFM19**	
Nominal velocity (m/μs):		**128.00**	
Object type	**Name**	**Intersection depth**	**Intersection angle**
PLANE	T	–14.8	17
PLANE	E	–11.3	16
PLANE	A	18.4	52
PLANE	C	29.8	24
PLANE	B1	30.2	56
PLANE	B	30.9	37
PLANE	D	44.2	42
PLANE	F	61.0	41
PLANE	G	70.7	46
PLANE	H	80.1	72
PLANE	I	102.9	46
PLANE	S	108.0	28
PLANE	J	110.0	52
PLANE	M	122.6	76
PLANE	L	125.9	19
PLANE	O	134.9	60
PLANE	K	138.4	10
PLANE	N	143.1	23
PLANE	P	150.2	73
PLANE	Q	159.4	57
PLANE	R	173.2	90
PLANE	V	239.8	22
PLANE	U	419.1	7

Names in table according to Appendix 5.

In Appendix 1 to 5, 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 material. A decrease in this amplitude may indicate fracture zones, clay or rock volumes with increases water content. The decrease in amplitude is seen for the following sections in KFM06A:

Depth (m)	**Depth (m)**
20–30	65
50	75

For HFM16:

Depth (m)	Depth (m)
60–65	75
70	85

For HFM17:

Depth (m)	Depth (m)
30	80–95
70	120

For HFM18:

Depth (m)	Depth (m)
10	95
35–40	130
45–50	135–145
80	

And for HFM19:

Depth (m)	Depth (m)
120–125	170–180
135	

5.2 BIPS logging

The BIPS pictures are presented in Appendix 6 to 11.

To get the best possible depth accuracy, the BIPS images are adjusted to the reference labels on the logging cable. The experience during the IPLU work is that these labels differ very little compared to the results from operations in core drilled boreholes. At present, the cable is labelled at 110, 150 and 200 m.

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 borehole. The resulting images displayed with 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 logging of KFM06A (0–100 m) was performed 03-12-03. The diameter of the borehole was at the time of logging 165 mm. The water quality and the visibility were far from perfect, but it is still possible, in at least parts of the borehole, to perform the geological mapping as long as there is a difference in colour and brightness between the lithological units. Thin fractures may however be difficult to map.

Logging of HFM16 was performed 03-12-04. The quality of the images is excellent; very seldom percussion drilled boreholes show this type of high quality images.

The borehole HFM17 has been logged twice. When the first run was performed, 04-01-15, the water quality below 31 m depth turned out to be very bad. From the first logging until the second run, 04-03-10, the conditions had changed dramatically and the second run gave perfect images along almost the entire borehole. Only in the lowermost part, a very thin layer of mud covers the borehole wall. This shows that, in most cases, it is preferable to log the boreholes a couple of weeks after the completion of drilling.

Logging of HFM18 was performed 04-01-15. The visibility within the upper part of the borehole was good. Some mud covering the lowermost part of the borehole wall was, however, decreasing the visibility. This effect gets stronger the deeper in the borehole but, in general, it should be easy to map even thin fractures and geological mapping should be possible indeed.

Logging of HFM19 was performed 04-01-16 and has a complete different quality problem compared to the other boreholes discussed in this report. In this borehole, the visibility is lowest in the mid part of the borehole, whilst in the shallowest and deepest parts the quality is reasonably, although not perfect.

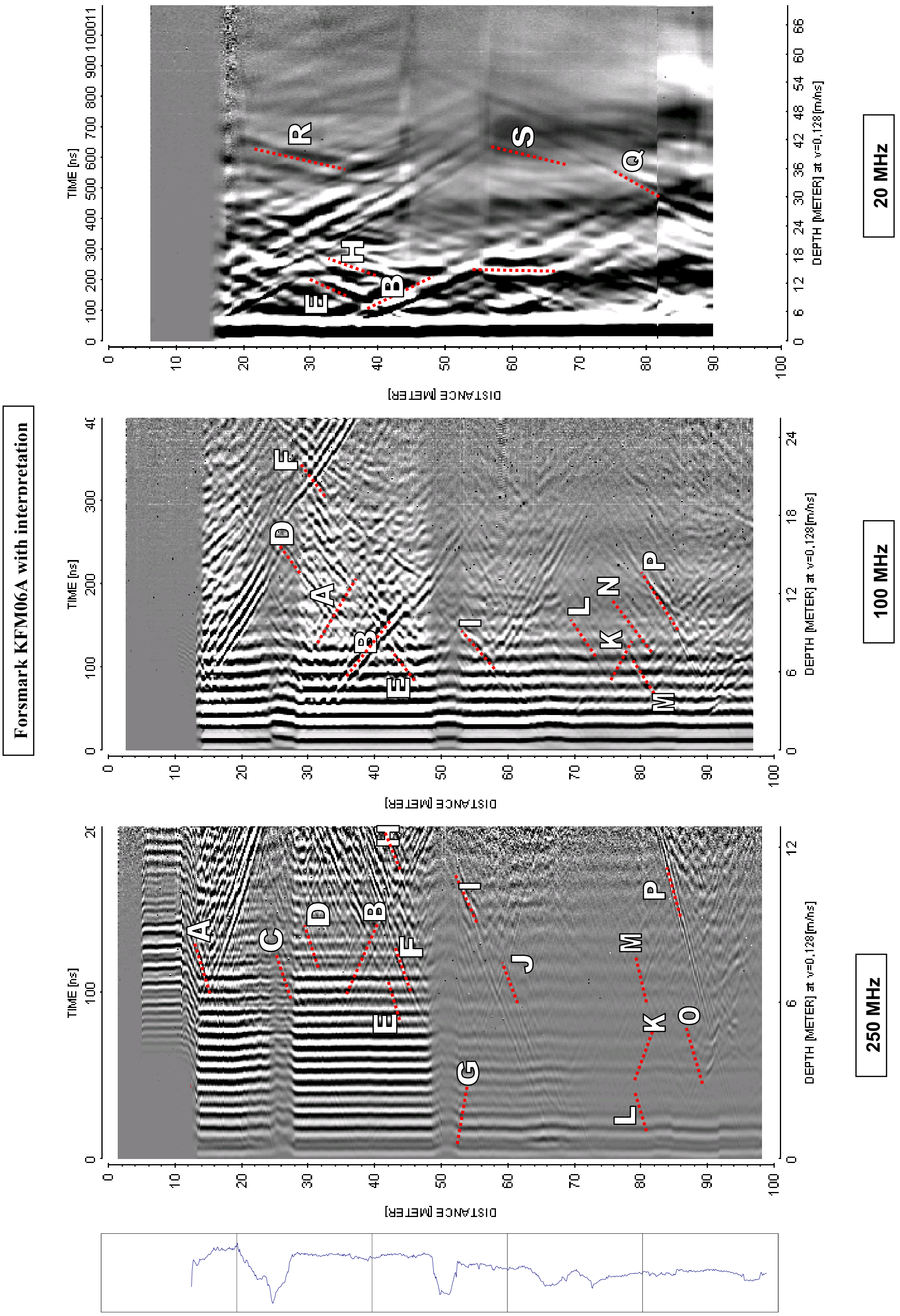
A re-logging was made 04-05-10 and the quality of the images was improved along almost the entire borehole. However, the images from the very deepest part, below c 170 m, came out very dark. When lifting the camera above 170 m, images of good quality was again achieved which, together with other tests performed, suggests that the effect seen is not related to an instrument failure. This effect has not been observed before and remains unexplained. The images from the previous logging (section 151-184 m) are presented in Appendix 11.

6 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.

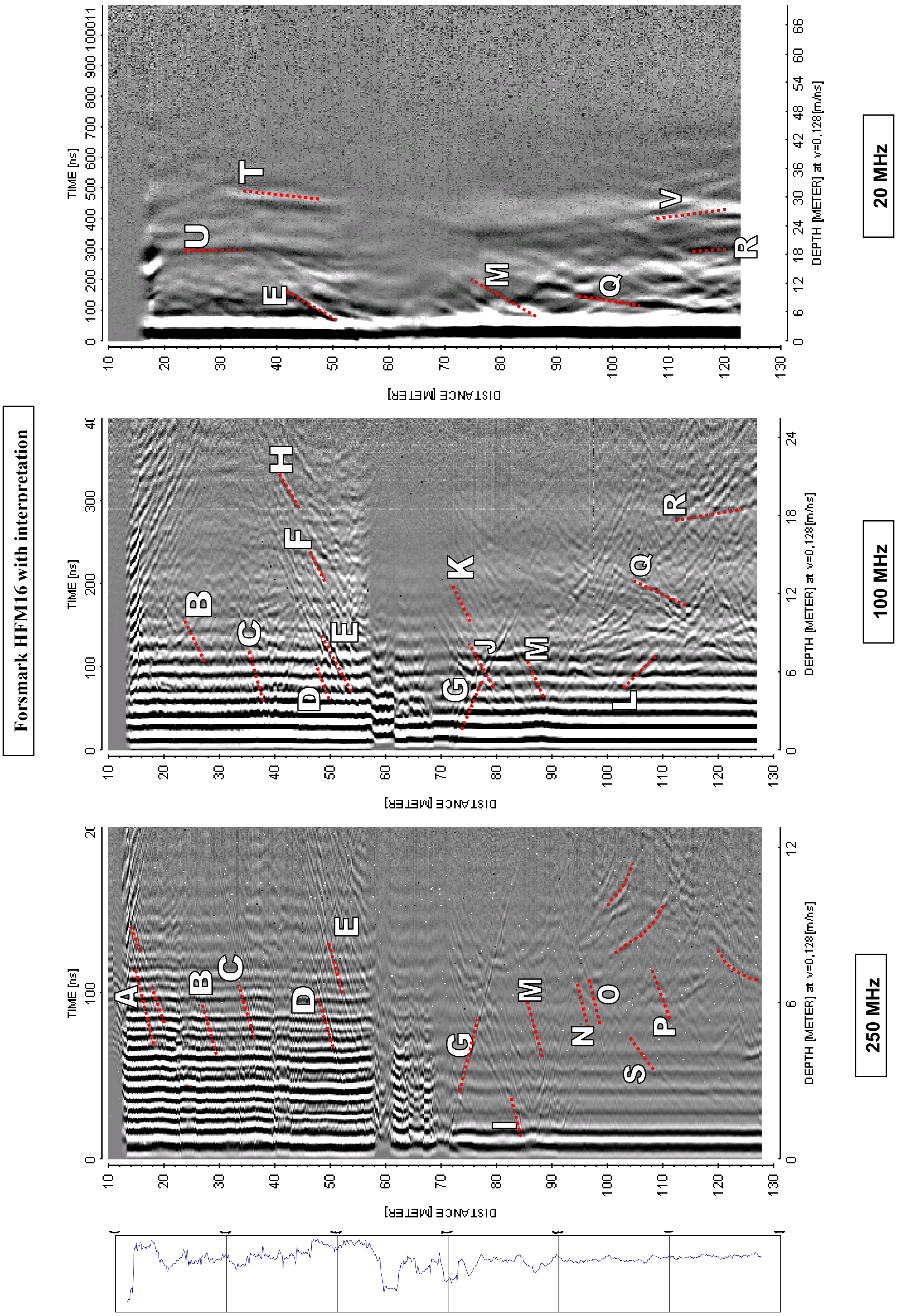
Radar logging of KFM06A, 0 to 100 m

Dipole antennas 250, 100 and 20 MHz



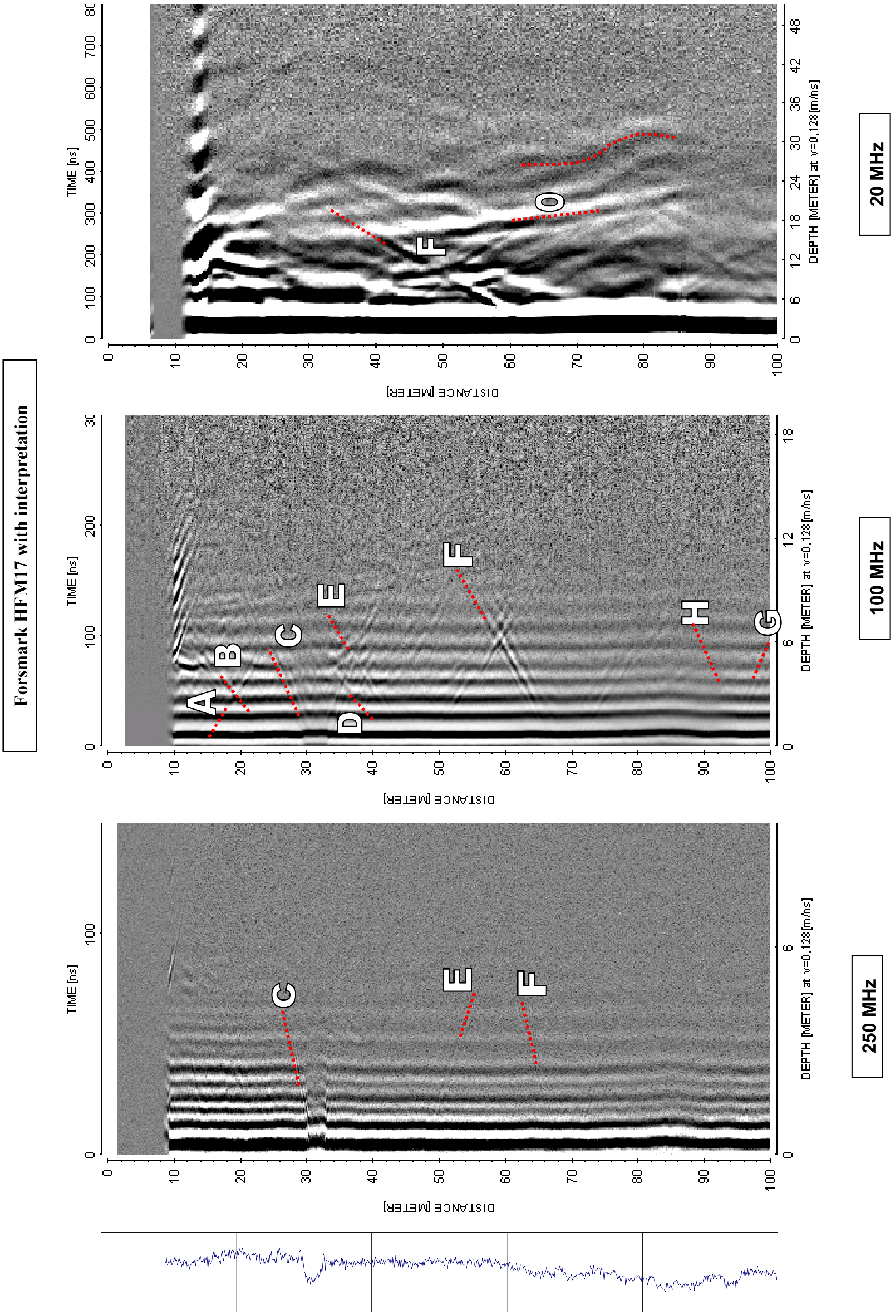
Radar logging of HFM16, 0 to 130 m

Dipole antennas 250, 100 and 20 MHz

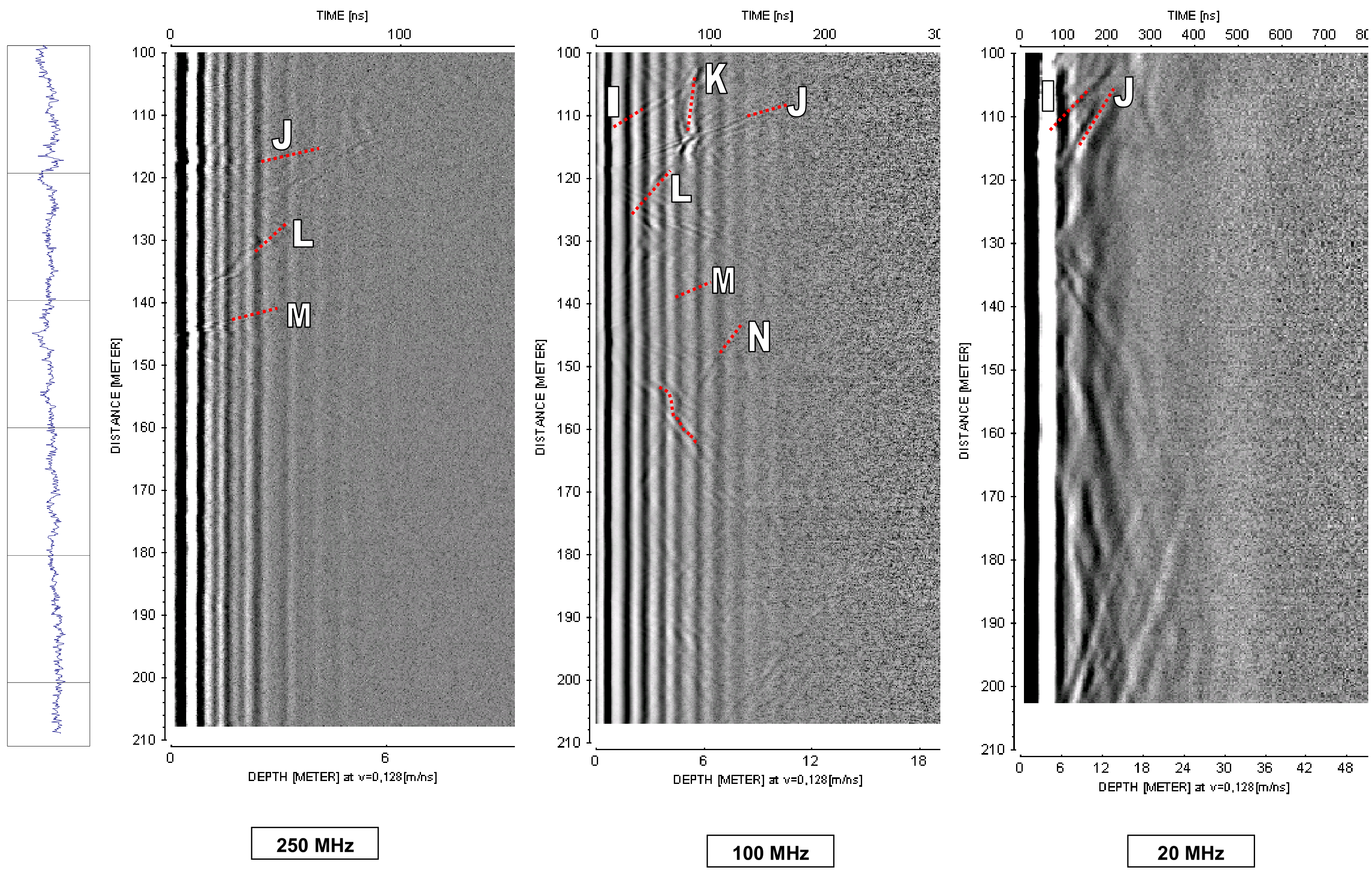


Radar logging of HFM17, 0 to 200 m

Dipole antennas 250, 100 and 20 MHz



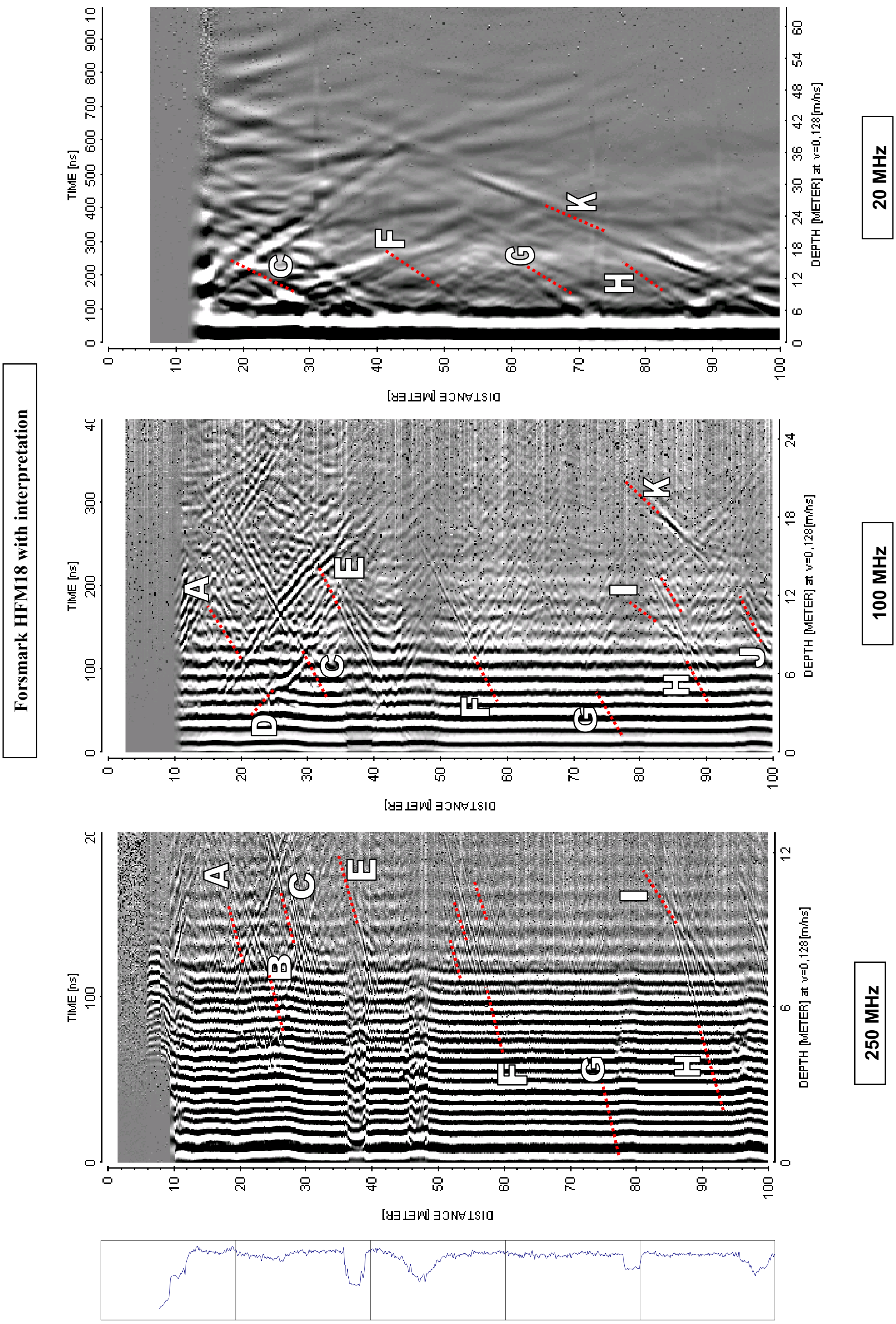
Forsmark HFM17 with interpretation



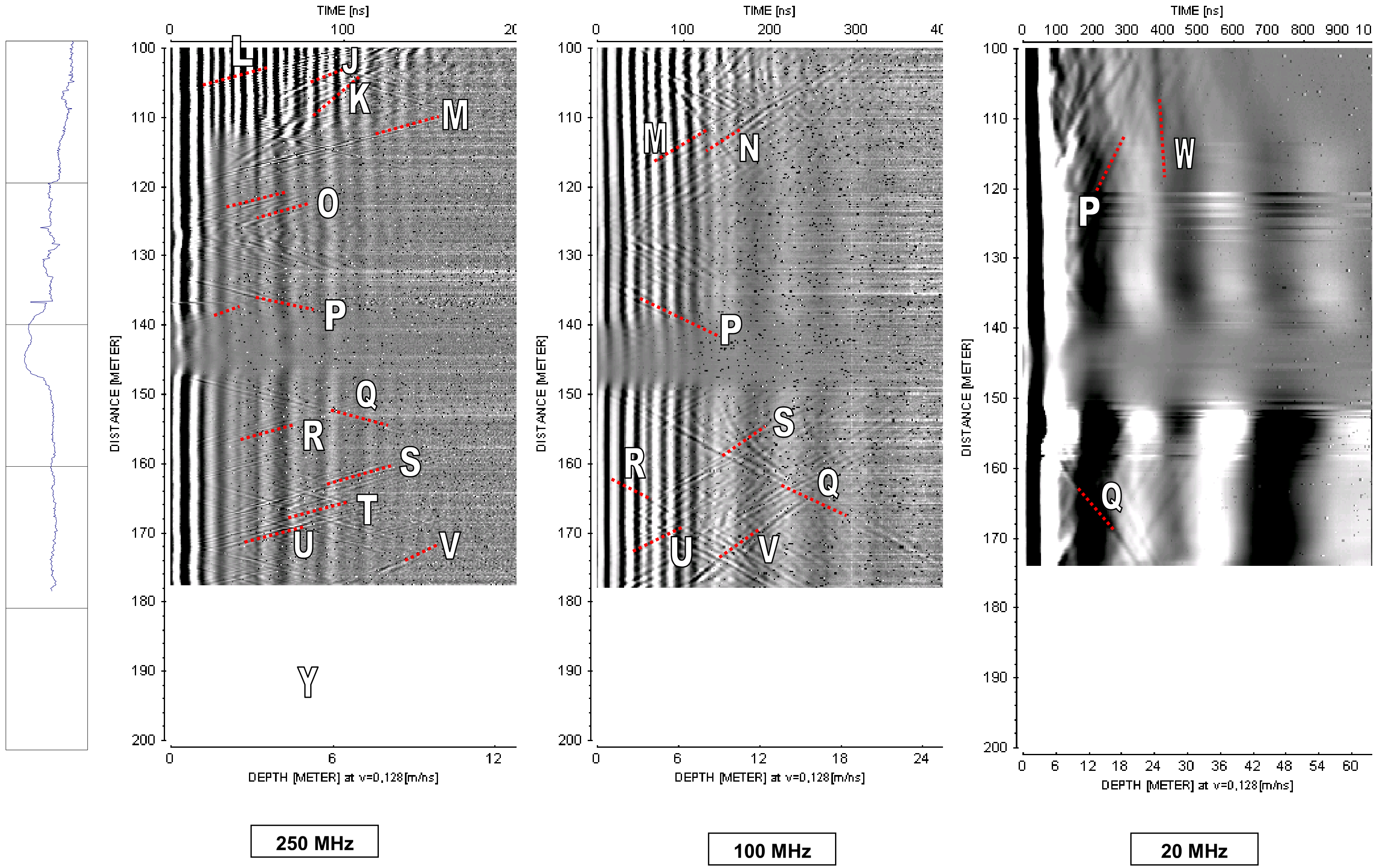
Appendix 4

Radar logging of HFM18, 0 to 180 m

Dipole antennas 250, 100 and 20 MHz

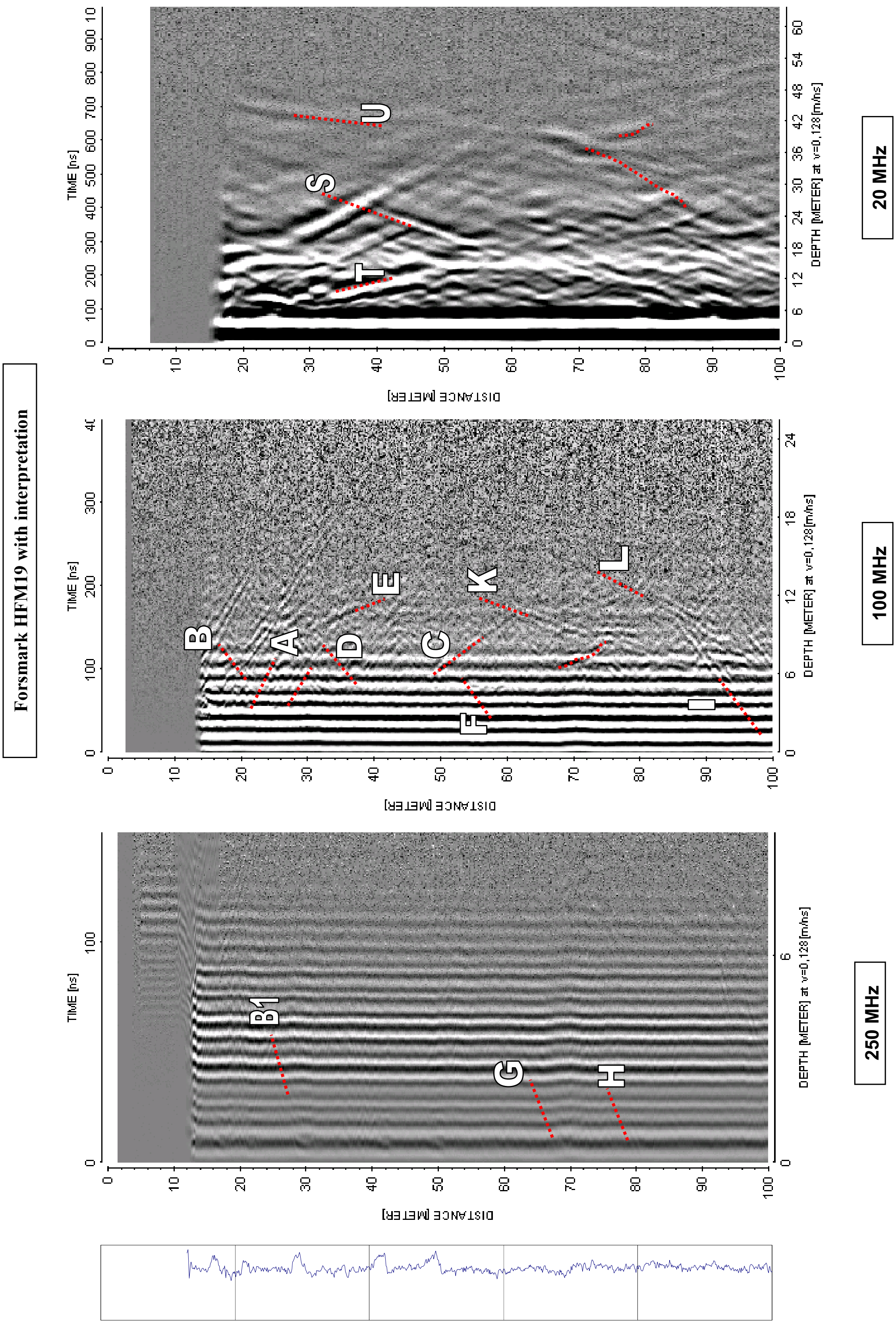


Forsmark HFM18 with interpretation

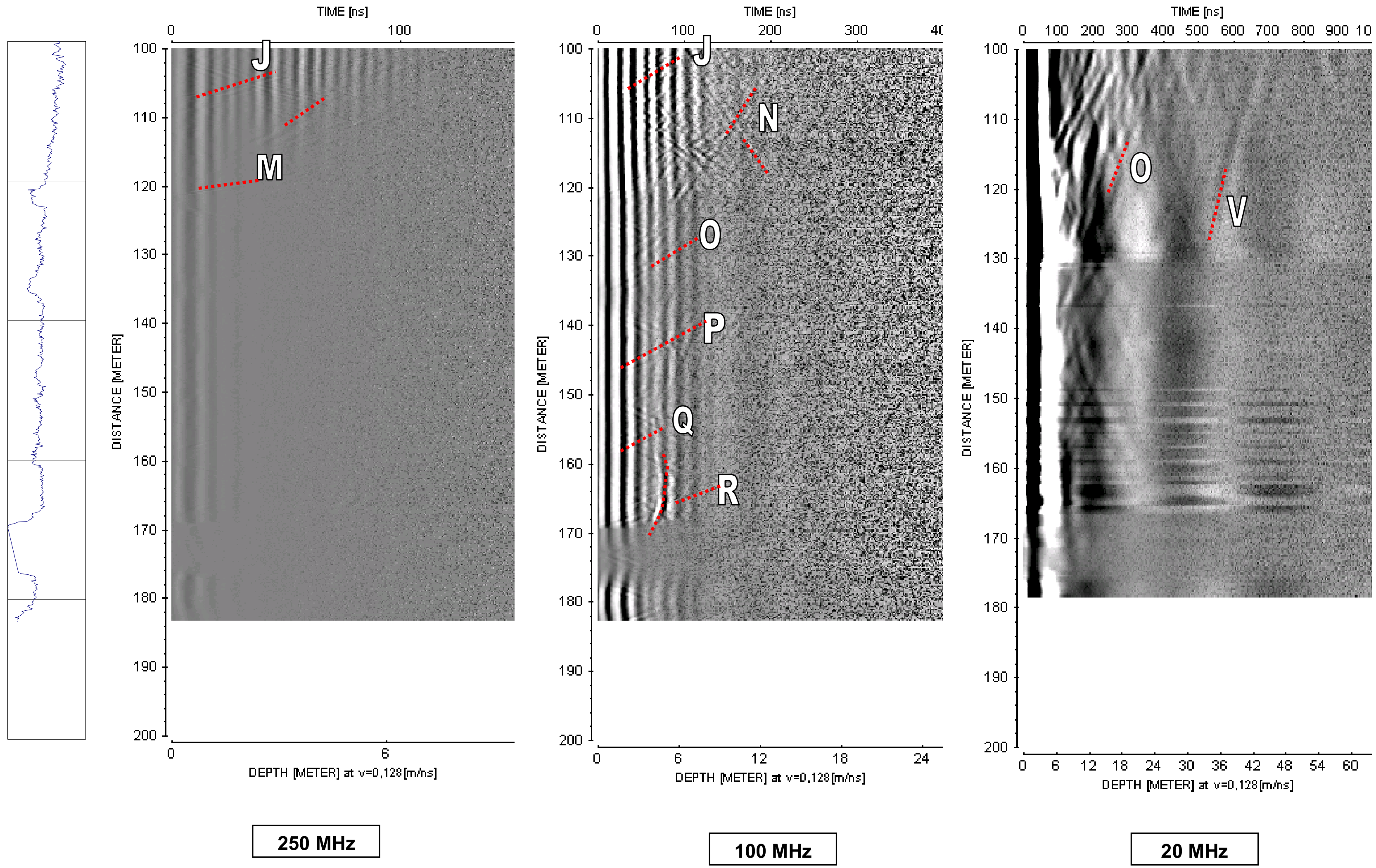


Radar logging of HFM19, 0 to 180 m

Dipole antennas 250, 100 and 20 MHz



Forsmark HFM19 with interpretation



Appendix 6

BIPS logging of KFM06A, 0–180 m

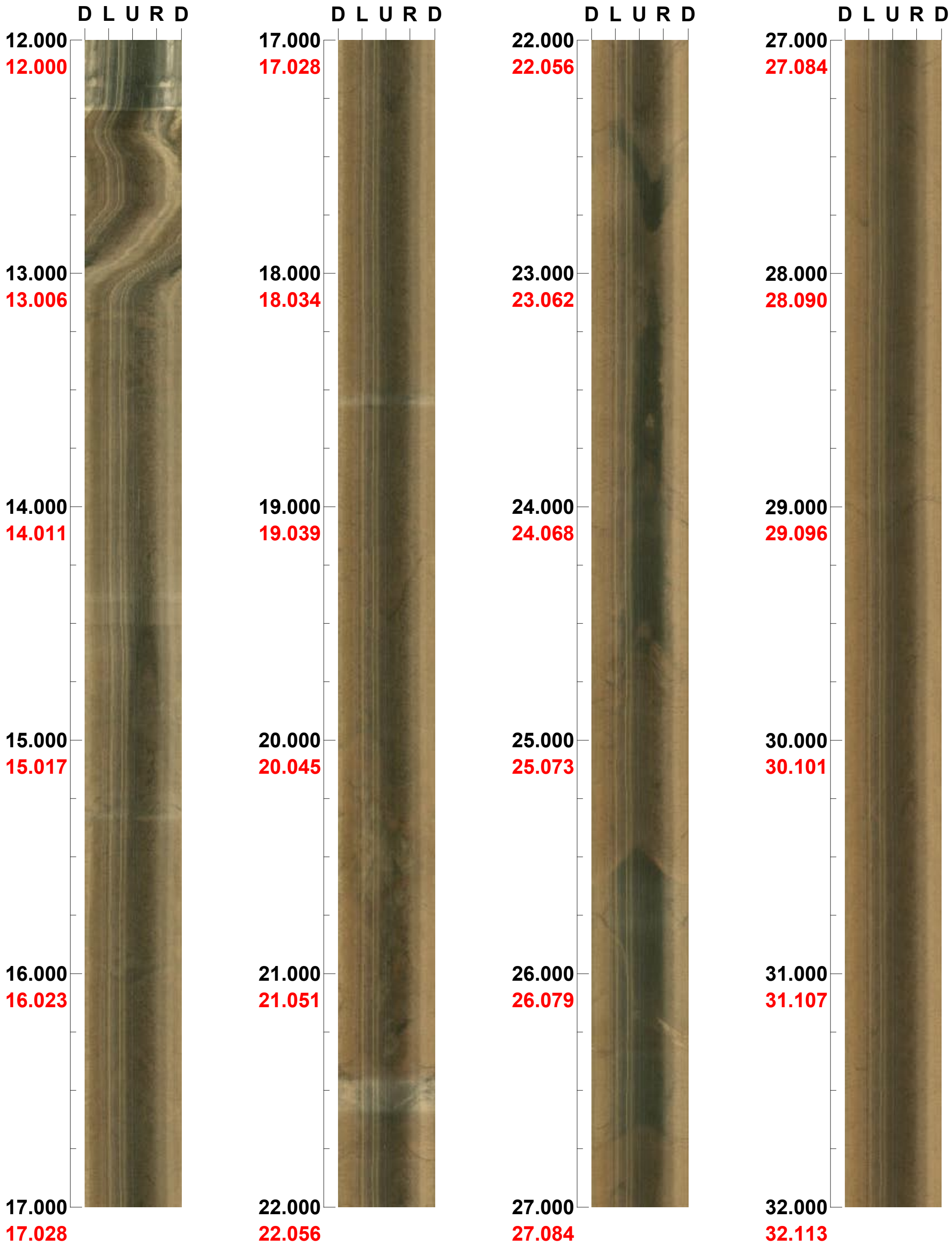
Project name: Forsmark

Image file	: c:\work\r5119s~2\kfm06a\0-100m\bips\kfm06a.bip
BDT file	: c:\work\r5119s~2\kfm06a\0-100m\bips\kfm06a.bdt
Locality	: FORSMARK
Bore hole number	: KFM06A
Date	: 03/12/03
Time	: 17:10:00
Depth range	: 12.000 - 99.358 m (red figures = corrected values)
Azimuth	: 0
Inclination	: -89
Diameter	: 165.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 80 %
Pages	: 5
Color	: +0 +0 +0

Project name: Forsmark

Bore hole No.: KFM06A **Azimuth: 0** **Inclination: -89**

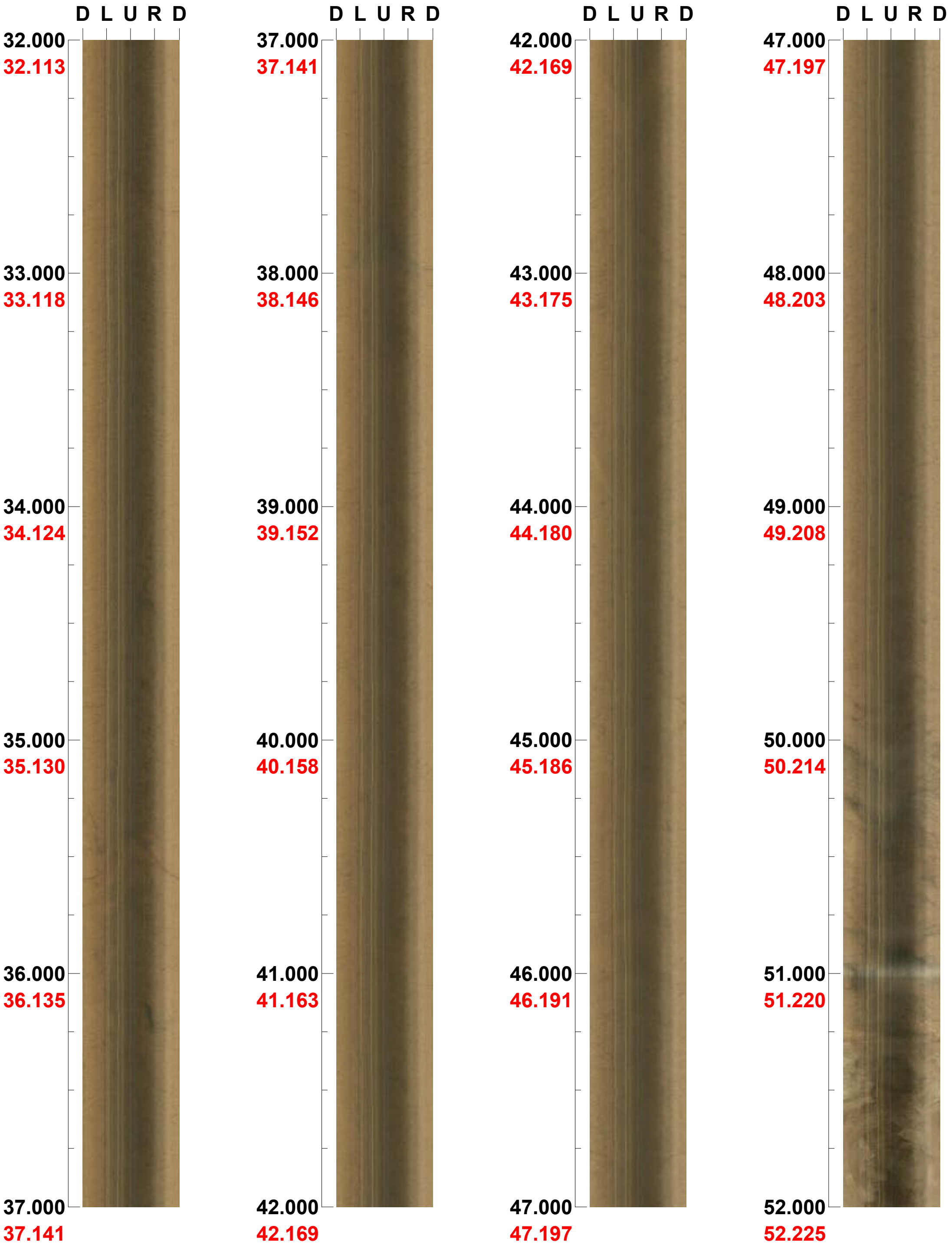
Depth range: 12.000 - 32.000 m



(1 / 5) **Scale: 1/25** **Aspect ratio: 80 %**

Project name: Forsmark
Bore hole No.: KFM06A **Azimuth: 0** **Inclination: -89**

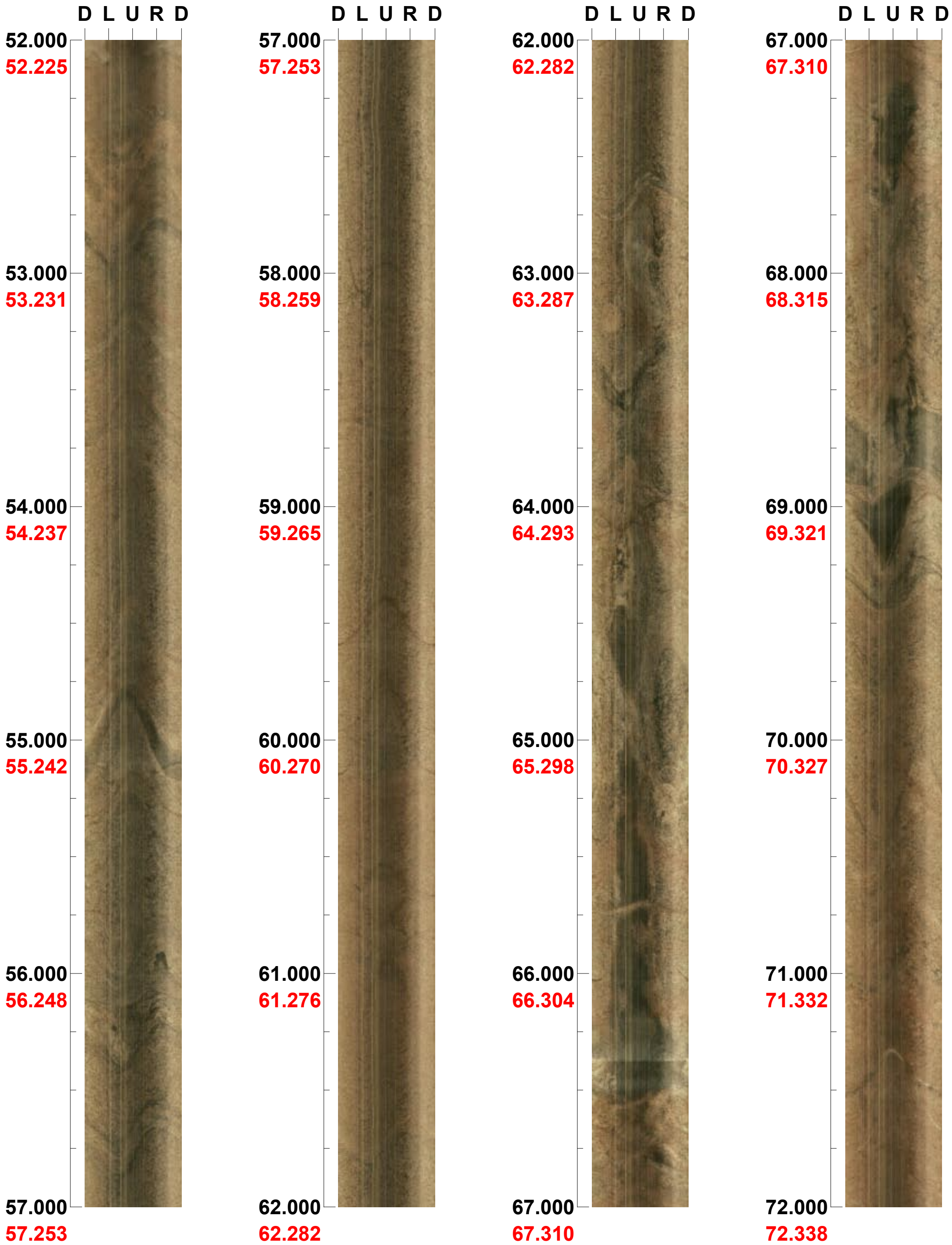
Depth range: 32.000 - 52.000 m



(2 / 5) **Scale: 1/25** **Aspect ratio: 80 %**

Project name: Forsmark
Bore hole No.: KFM06A **Azimuth: 0** **Inclination: -89**

Depth range: 52.000 - 72.000 m



(3 / 5) **Scale: 1/25** **Aspect ratio: 80 %**

Project name: Forsmark
Bore hole No.: KFM06A **Azimuth: 0** **Inclination: -89**

Depth range: 72.000 - 92.000 m

(4 / 5) **Scale: 1/25** **Aspect ratio: 80 %**

Project name: Forsmark

Bore hole No.: KFM06A **Azimuth: 0** **Inclination: -89**

Depth range: 92.000 - 99.358 m

(5 / 5) **Scale: 1/25** **Aspect ratio: 80 %**

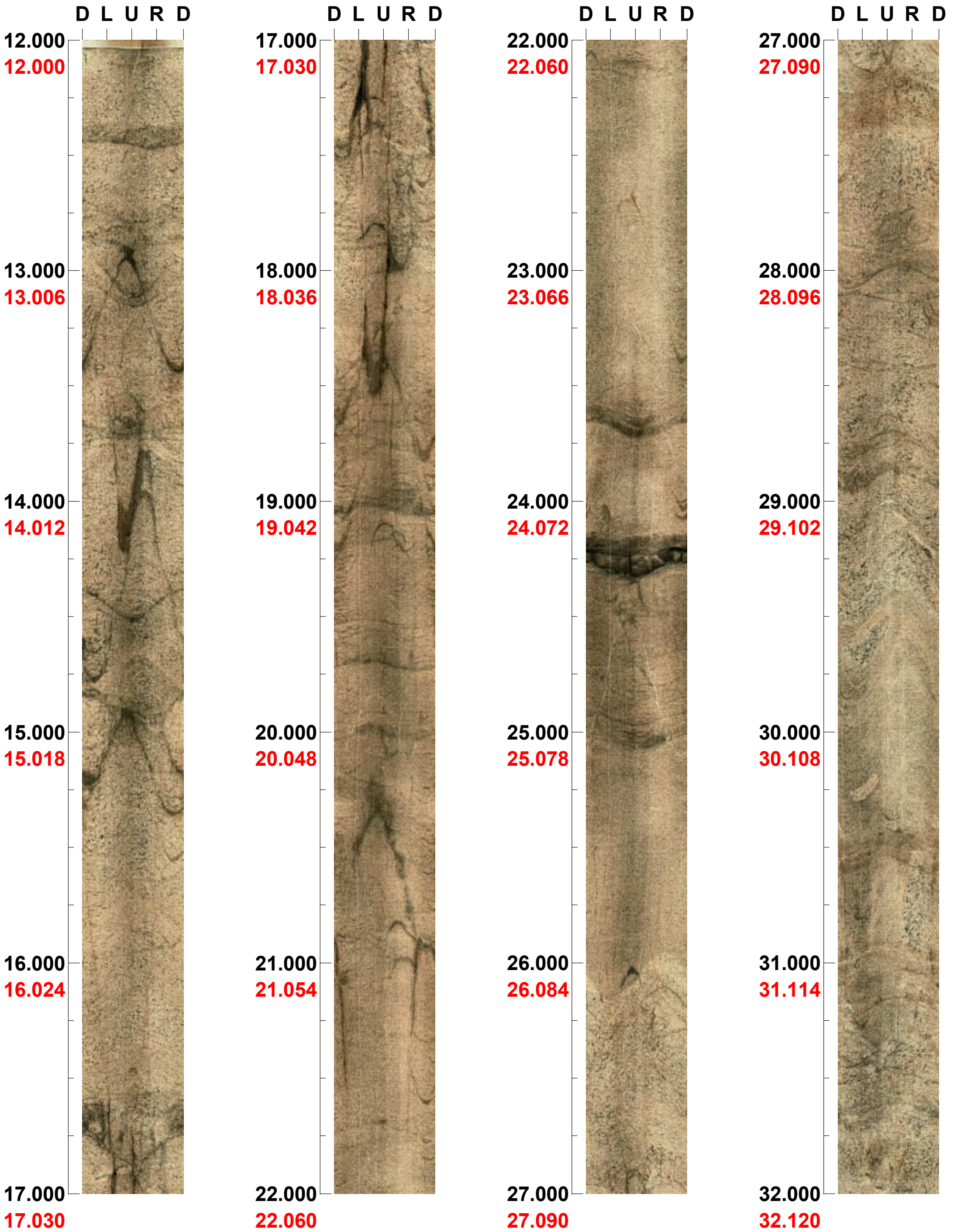
BIPS logging of HFM16, 12–128.9 m

Project name: Forsmark

Image file	: h:\work\hfm16\bips\hfm16.bip
BDT file	: h:\work\hfm16\bips\hfm16.bdt
Locality	: FORSMARK
Bore hole number	: HFM16
Date	: 03/12/04
Time	: 10:50:00
Depth range	: 12.000 - 128.879 m (red figures = corrected values)
Azimuth	: 328
Inclination	: -84
Diameter	: 140.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 100 %
Pages	: 6
Color	: +0 +0 +0

Project name: Forsmark
Bore hole No.: HFM16 **Azimuth: 328** **Inclination: -84**

Depth range: 12.000 - 32.000 m



(1 / 6) **Scale: 1/25** **Aspect ratio: 100 %**

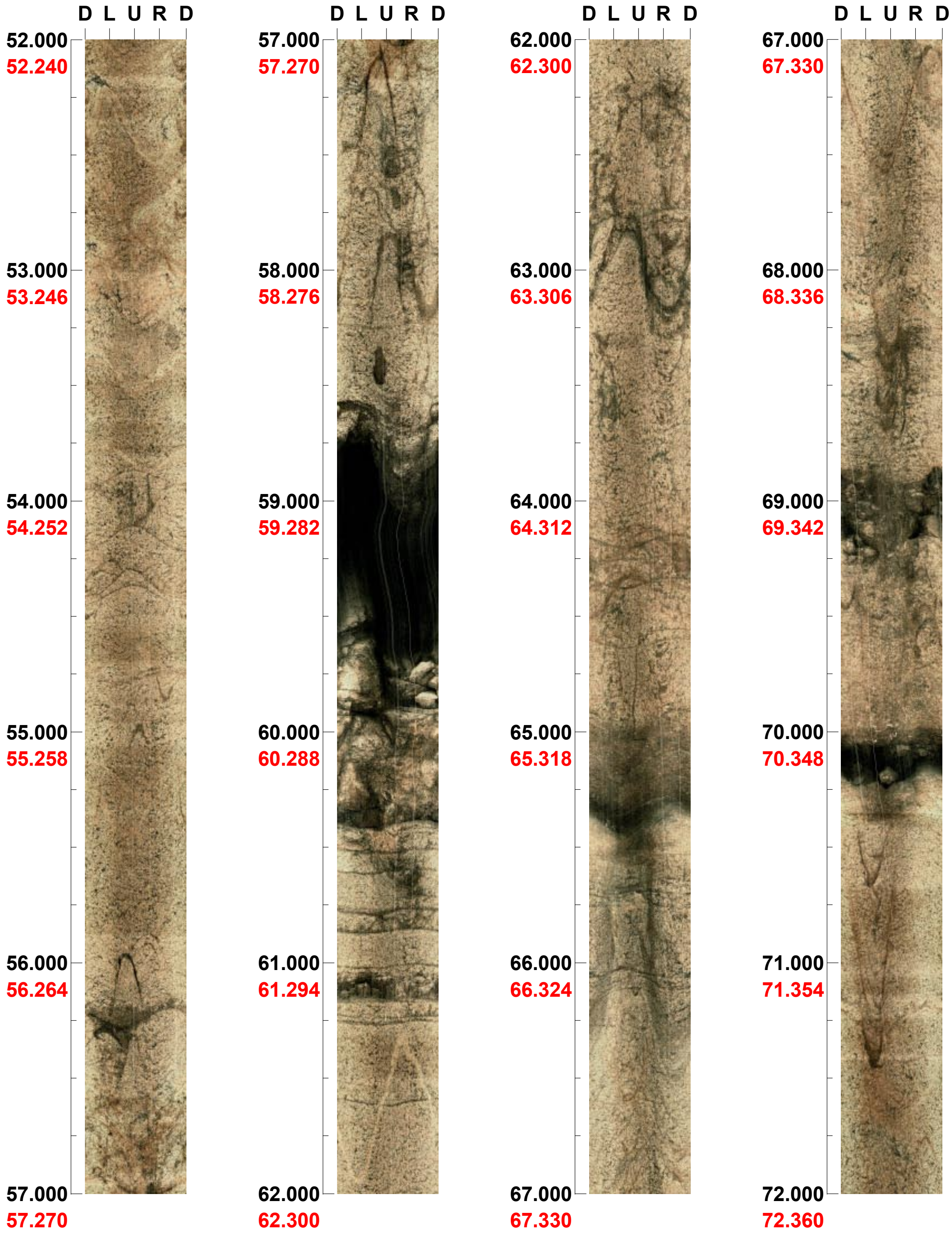
Project name: Forsmark
Bore hole No.: HFM16 **Azimuth: 328** **Inclination: -84**

Depth range: 32.000 - 52.000 m

(2 / 6) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark
Bore hole No.: HFM16 **Azimuth: 328** **Inclination: -84**

Depth range: 52.000 - 72.000 m



(3 / 6) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark
Bore hole No.: HFM16 **Azimuth: 328** **Inclination: -84**

Depth range: 72.000 - 92.000 m

(4 / 6) Scale: 1/25 Aspect ratio: 100 %

Project name: Forsmark
Bore hole No.: HFM16 **Azimuth: 328** **Inclination: -84**

Depth range: 92.000 - 112.000 m

(5 / 6) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

Bore hole No.: HFM16 **Azimuth: 328** **Inclination: -84**

Depth range: 112.000 - 128.879 m

(6 / 6) Scale: 1/25 Aspect ratio: 100 %

Appendix 8

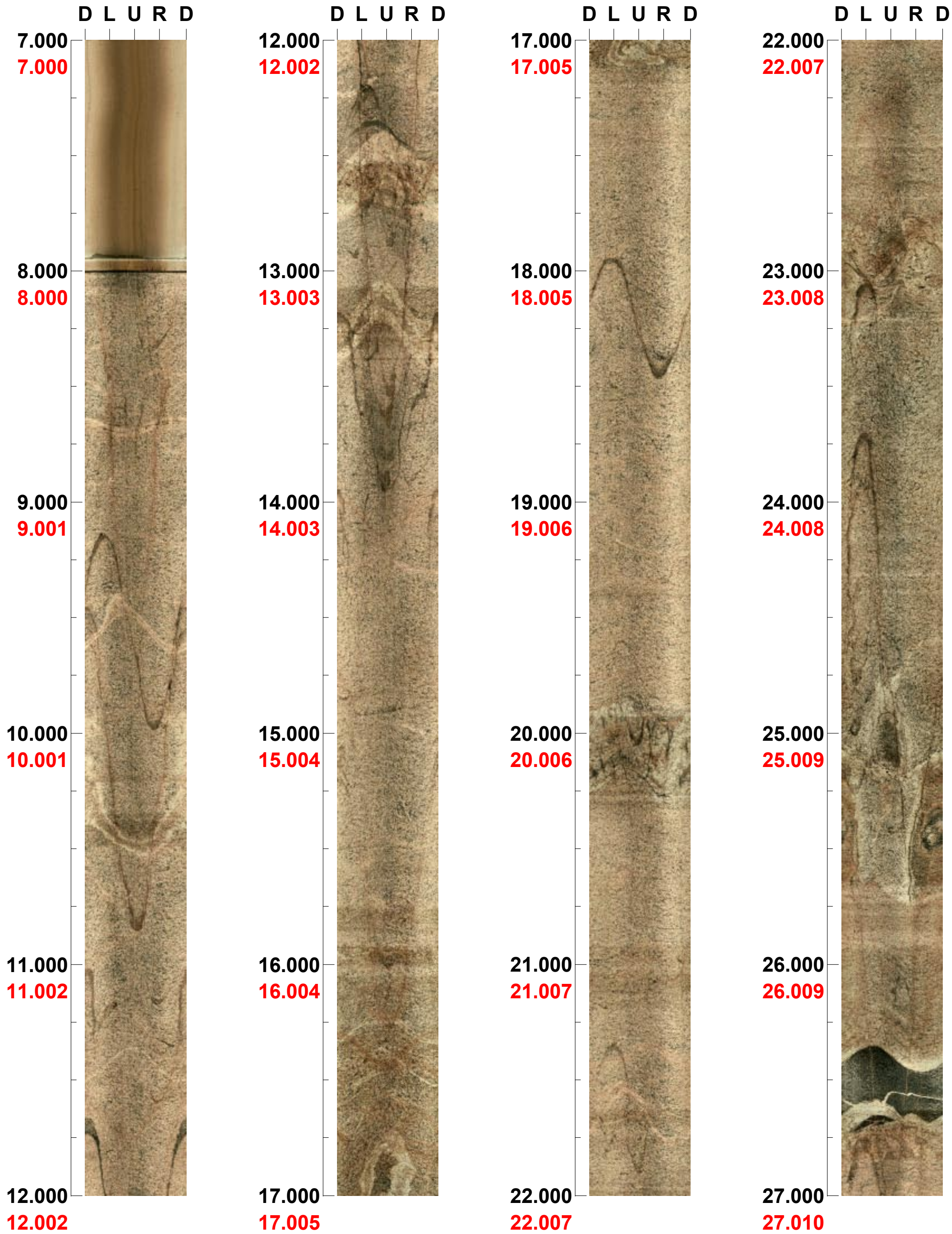
BIPS logging of HFM17, 7–208.3 m

Project name: Forsmark

Image file	: h:\work\hfm17\bips\bipsom~1\hfm17.bip
BDT file	: h:\work\hfm17\bips\bipsom~1\hfm17.bdt
Locality	: FORSMARK
Bore hole number	: HFM17
Date	: 04/03/10
Time	: 16:43:00
Depth range	: 7.000 - 208.225 m (red figures = corrected values)
Azimuth	: 320
Inclination	: -85
Diameter	: 140.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 100 %
Pages	: 11
Color	: +0 +0 +0

Project name: Forsmark
Bore hole No.: HFM17 **Azimuth: 320** **Inclination: -85**

Depth range: 7.000 - 27.000 m



(1 / 11) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark
Bore hole No.: HFM17 **Azimuth: 320** **Inclination: -85**

Depth range: 27.000 - 47.000 m

(2 / 11) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

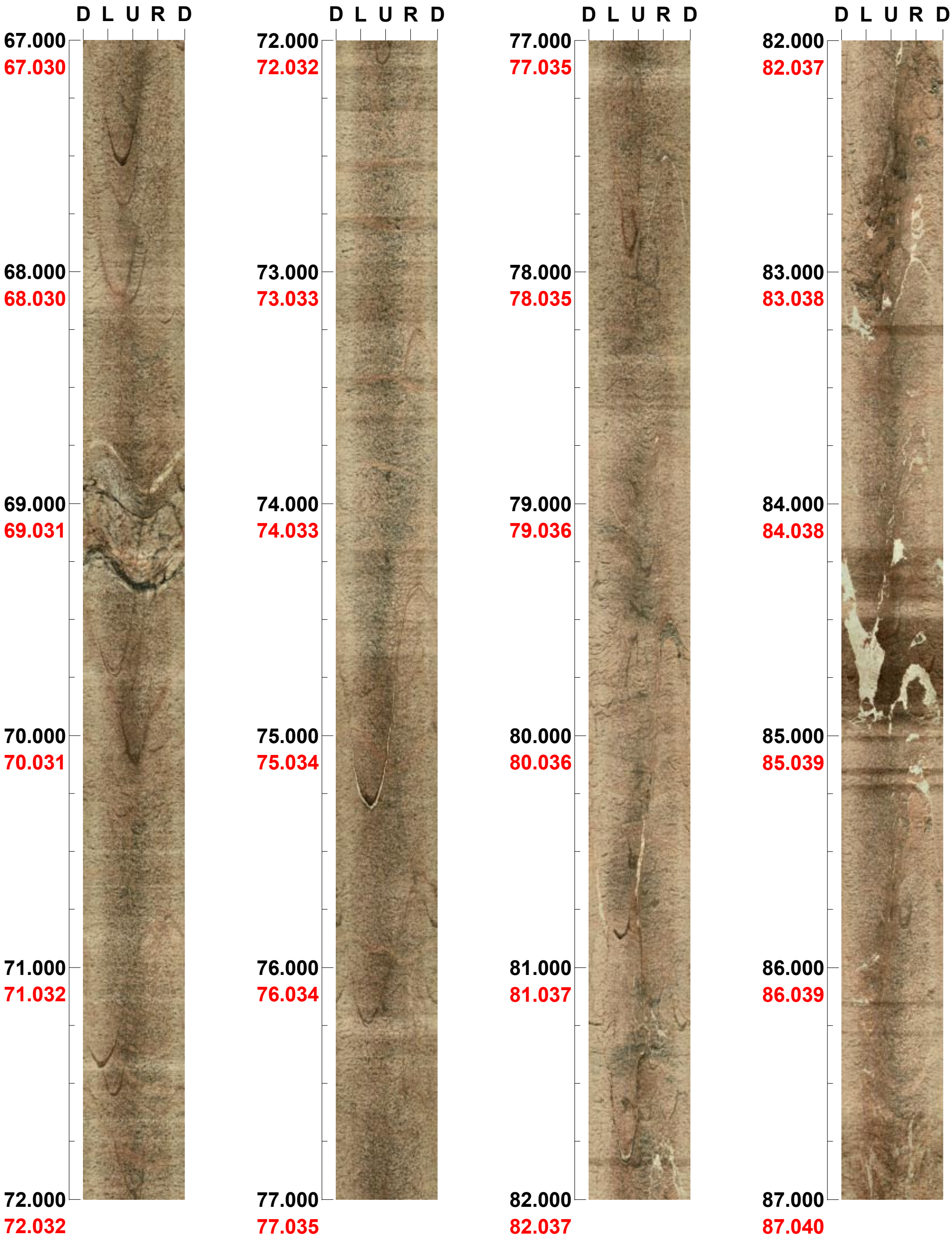
Bore hole No.: HFM17 **Azimuth: 320** **Inclination: -85**

Depth range: 47.000 - 67.000 m

(3 / 11) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark
Bore hole No.: HFM17 Azimuth: 320 Inclination: -85

Depth range: 67.000 - 87.000 m

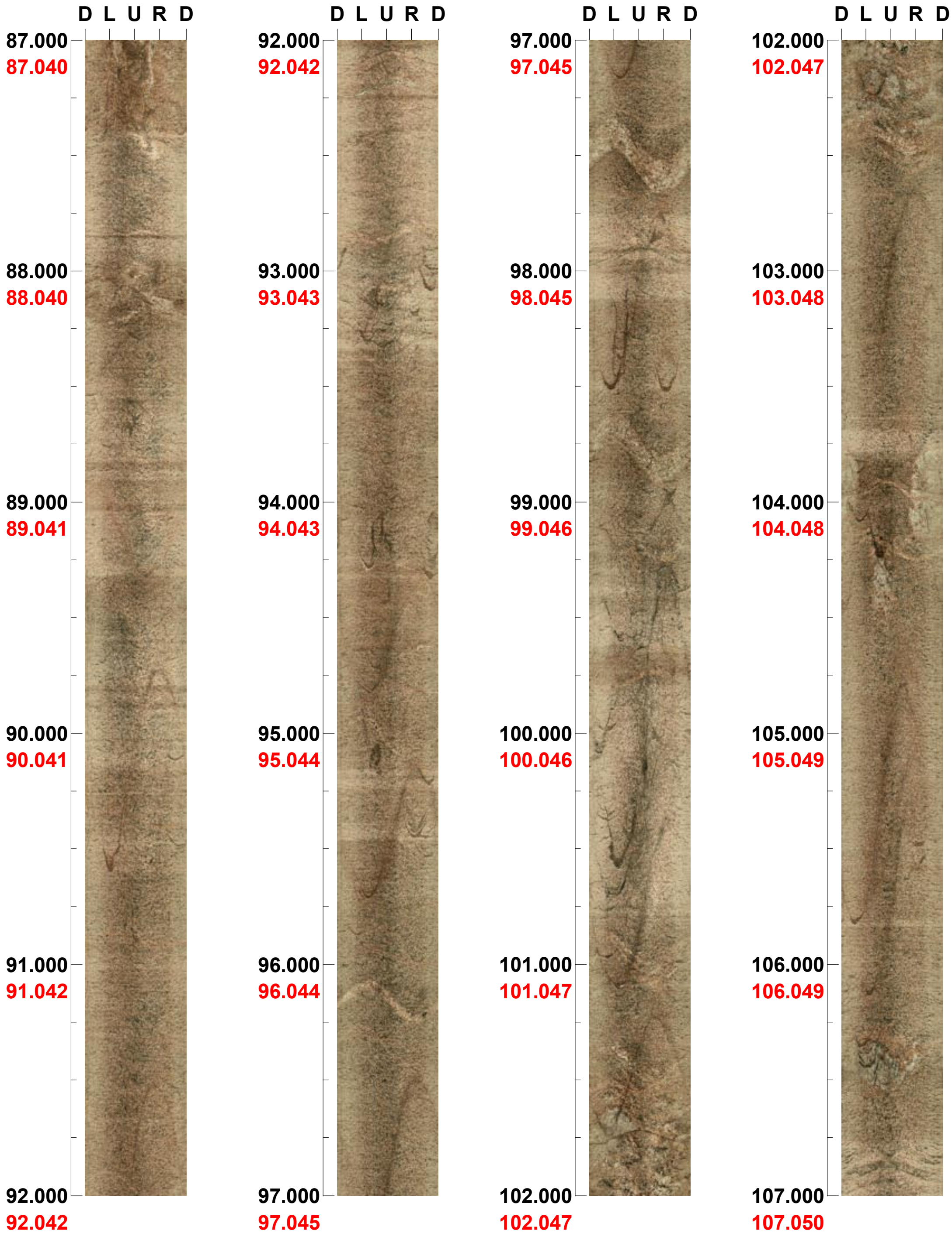


(4 / 11) Scale: 1/25 Aspect ratio: 100 %

Project name: Forsmark

Bore hole No.: HFM17 **Azimuth: 320** **Inclination: -85**

Depth range: 87.000 - 107.000 m



(5 / 11) **Scale: 1/25** **Aspect ratio: 100 %**

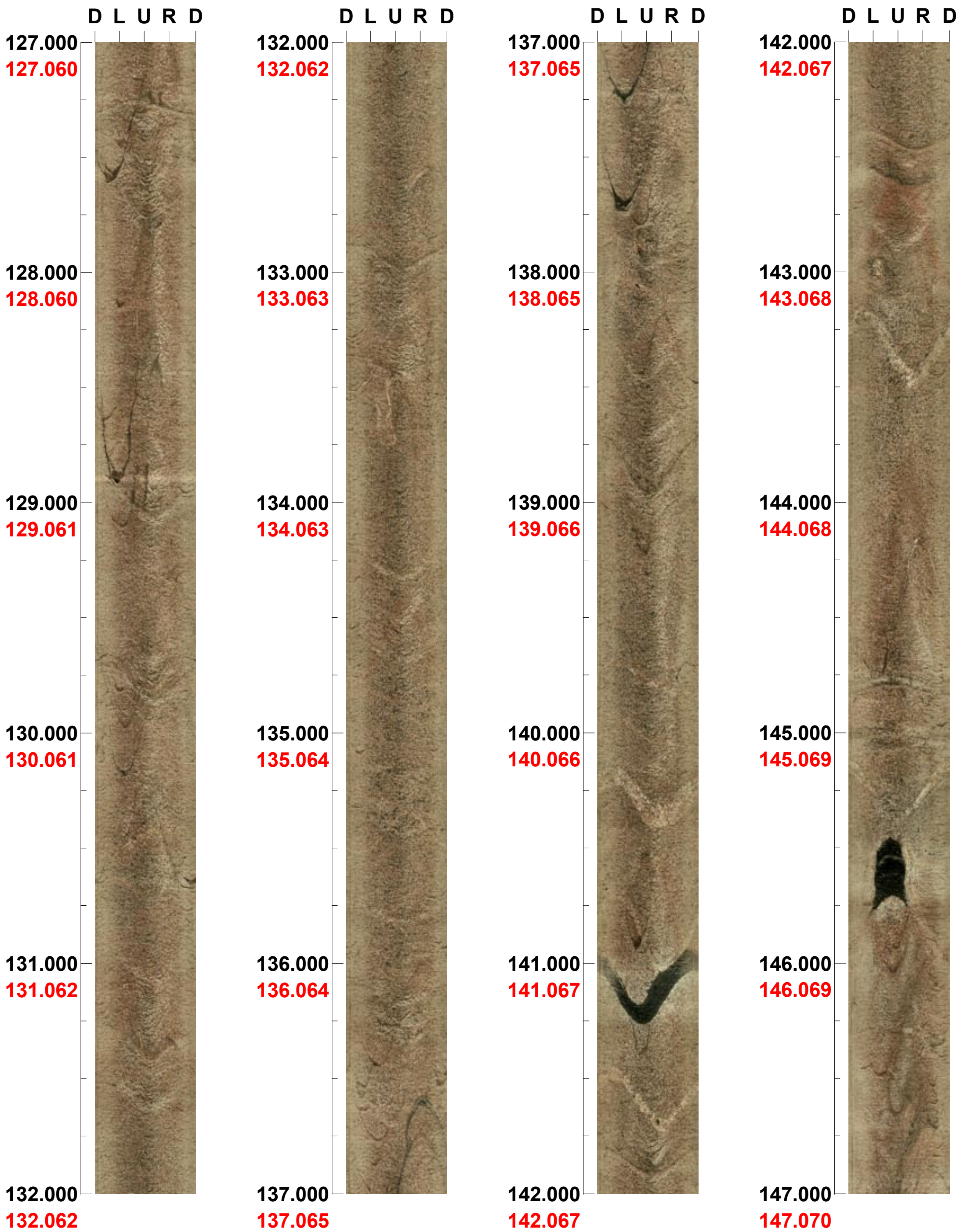
Project name: Forsmark
Bore hole No.: HFM17 **Azimuth: 320** **Inclination: -85**

Depth range: 107.000 - 127.000 m

(6 / 11) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark
Bore hole No.: HFM17 **Azimuth: 320** **Inclination: -85**

Depth range: 127.000 - 147.000 m

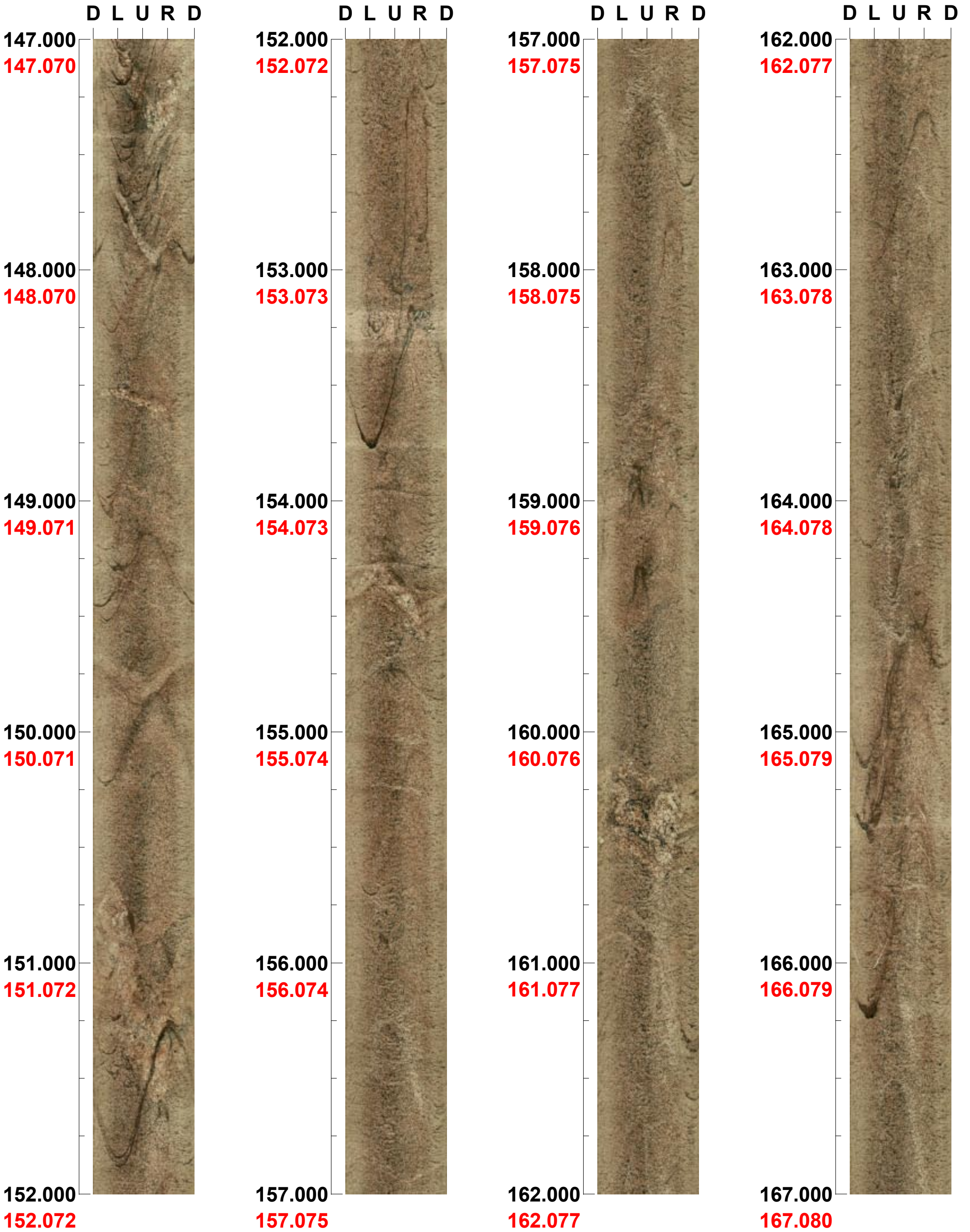


(7 / 11) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

Bore hole No.: HFM17 **Azimuth: 320** **Inclination: -85**

Depth range: 147.000 - 167.000 m

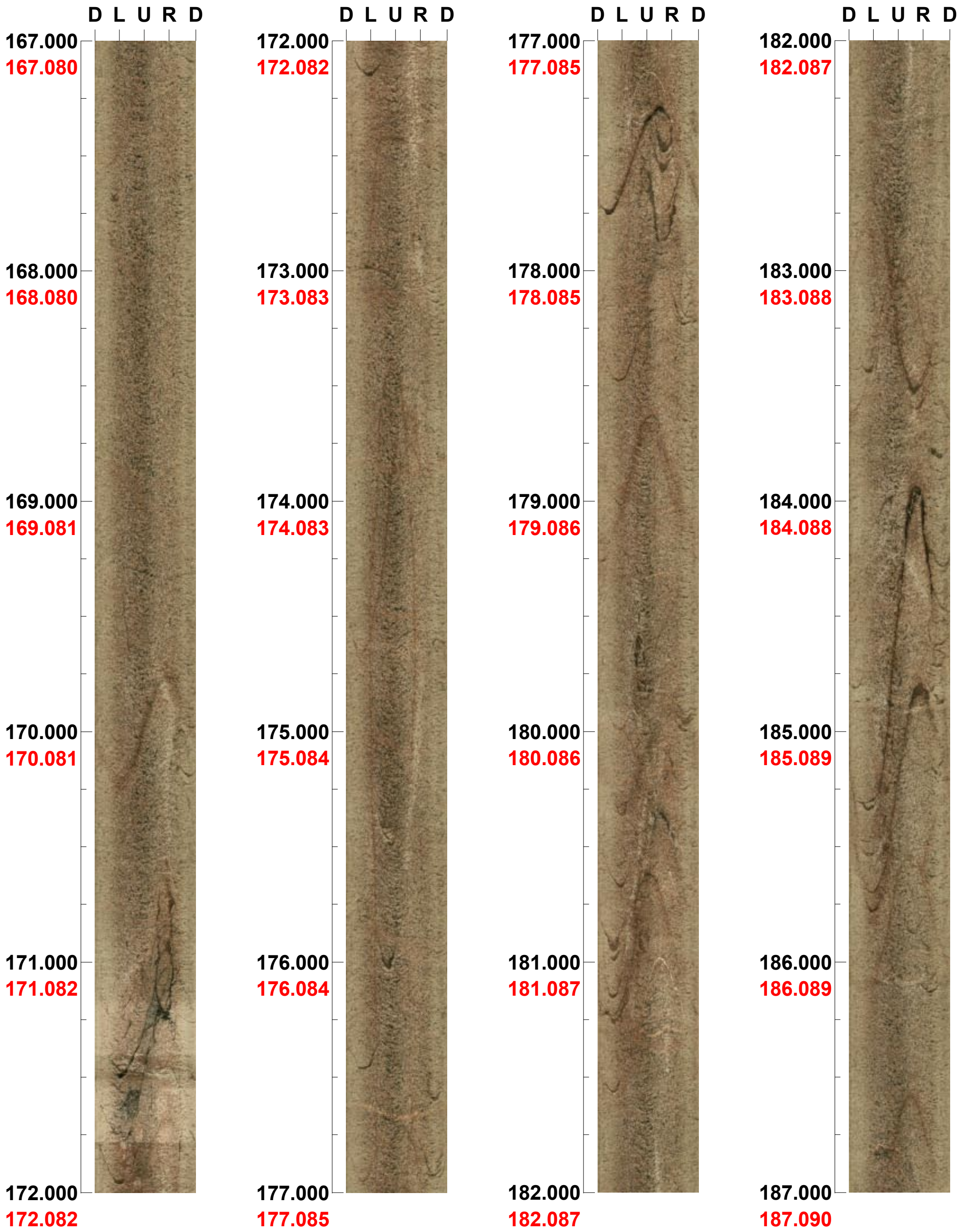


(8 / 11) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

Bore hole No.: HFM17 **Azimuth: 320** **Inclination: -85**

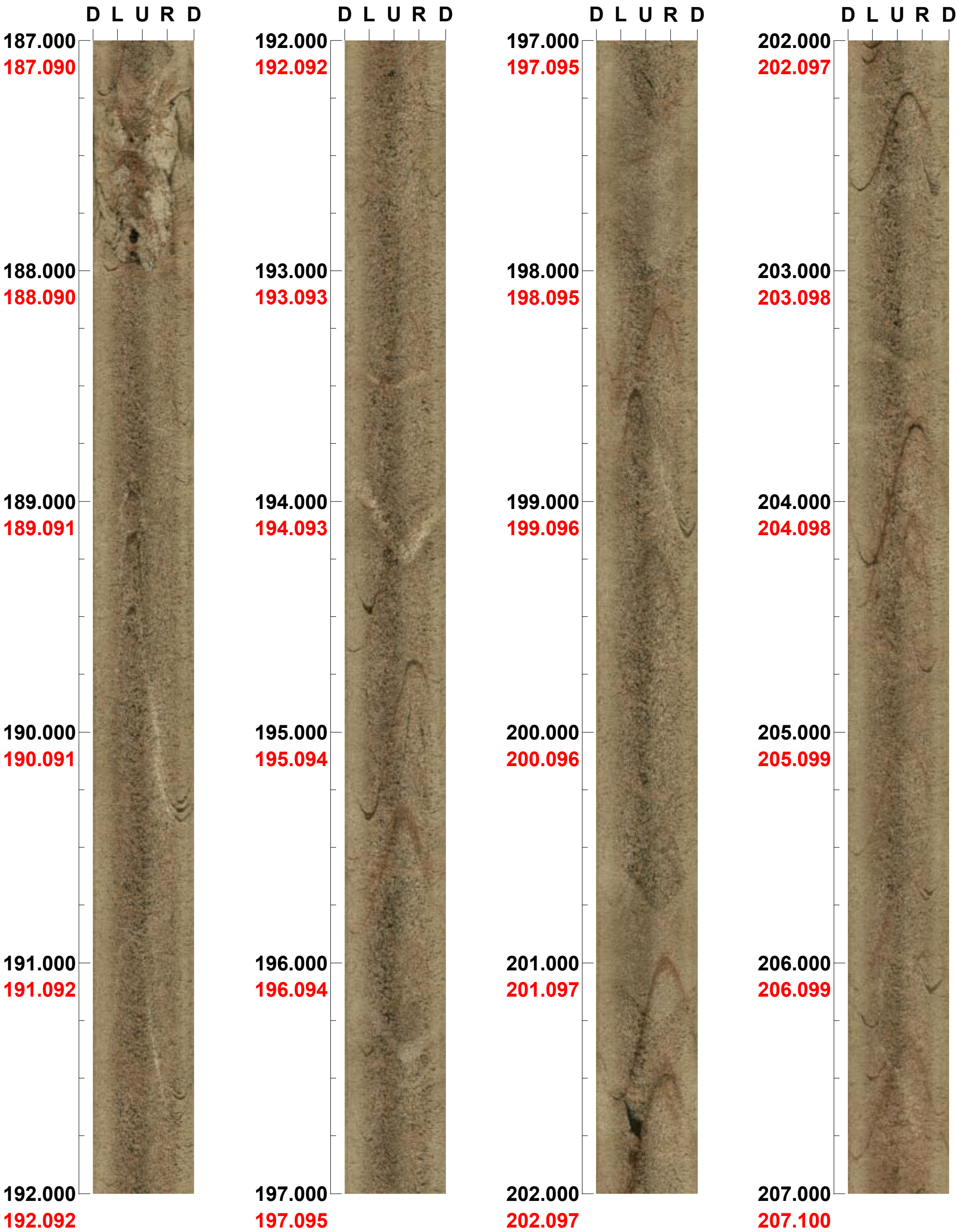
Depth range: 167.000 - 187.000 m



(9 / 11) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark
Bore hole No.: HFM17 **Azimuth: 320** **Inclination: -85**

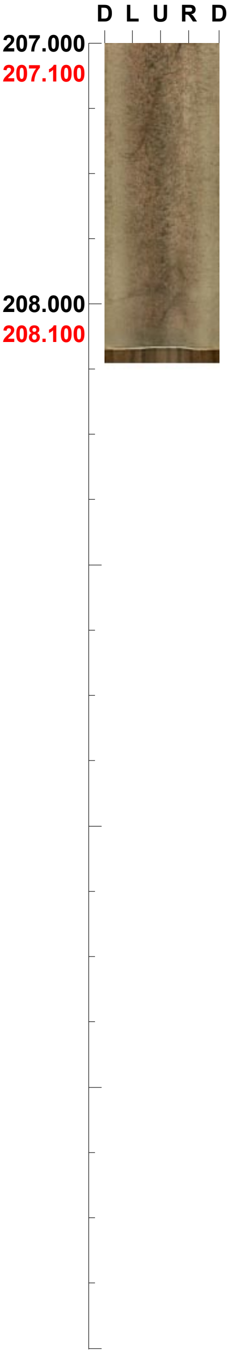
Depth range: 187.000 - 207.000 m



(10 / 11) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark
Bore hole No.: HFM17 Azimuth: 320 Inclination: -85

Depth range: 207.000 - 208.225 m



(11 / 11) Scale: 1/25 Aspect ratio: 100 %

Appendix 9

BIPS logging of HFM18, 8–179.5 m

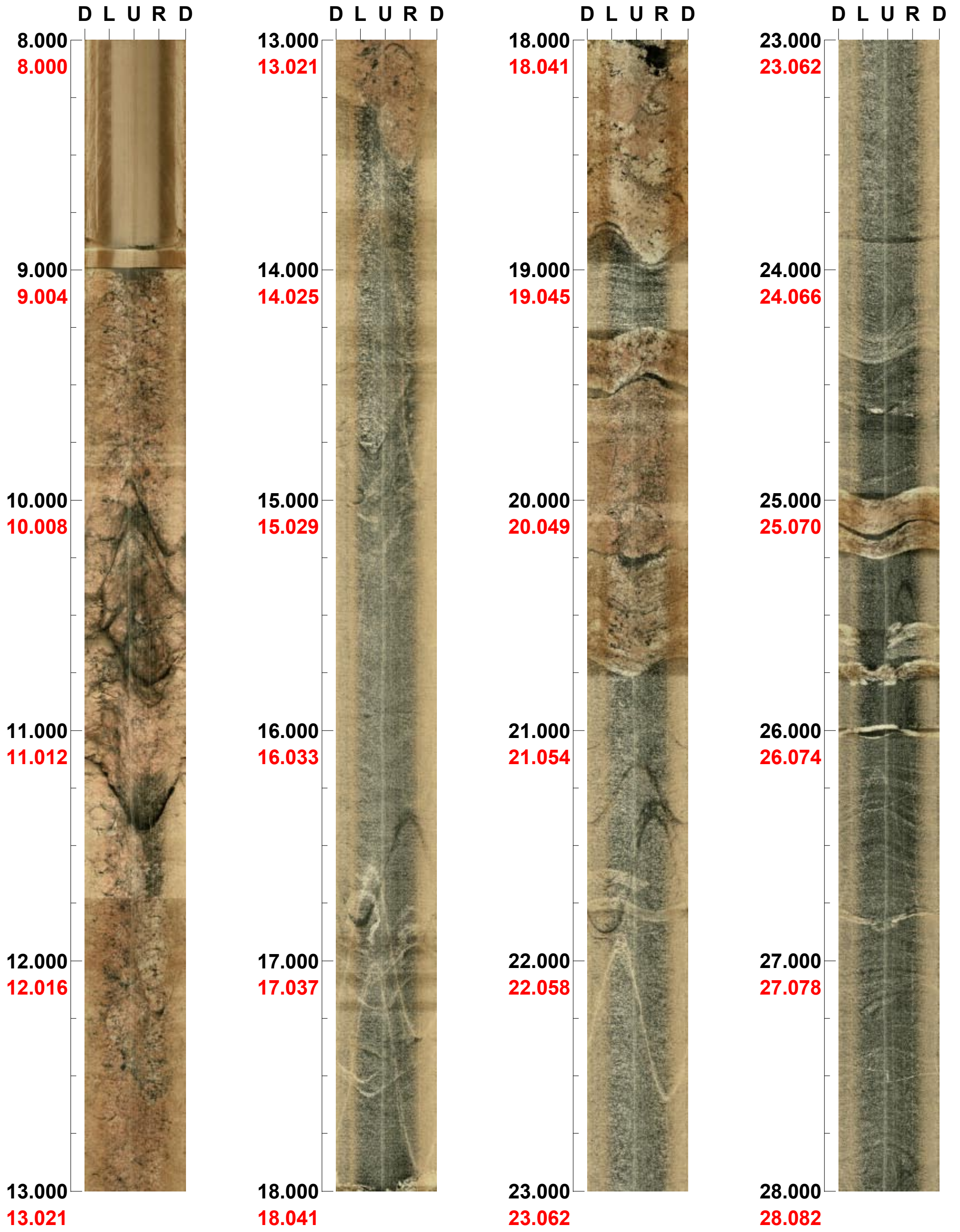
Project name: Forsmark

Image file	: h:\work\hfm18\bips\hfm18.bip
BDT file	: h:\work\hfm18\bips\hfm18.bdt
Locality	: FORSMARK
Bore hole number	: HFM18
Date	: 04/01/15
Time	: 09:07:00
Depth range	: 8.000 - 179.441 m (red figures = corrected values)
Azimuth	: 315
Inclination	: -60
Diameter	: 140.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 100 %
Pages	: 9
Color	: +0 +0 +0

Project name: Forsmark

Bore hole No.: HFM18 **Azimuth: 315** **Inclination: -60**

Depth range: 8.000 - 28.000 m

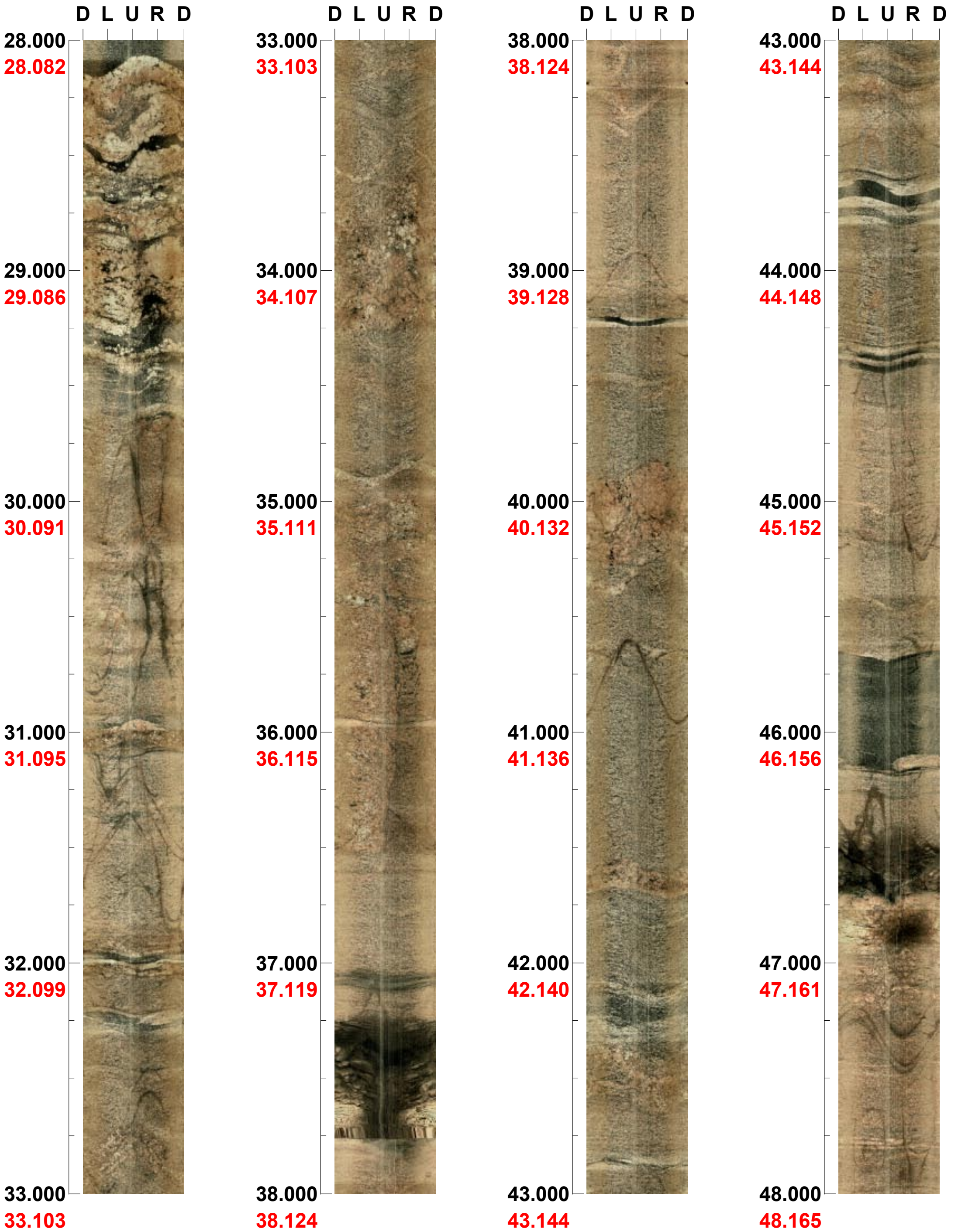


(1 / 9) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

Bore hole No.: HFM18 **Azimuth: 315** **Inclination: -60**

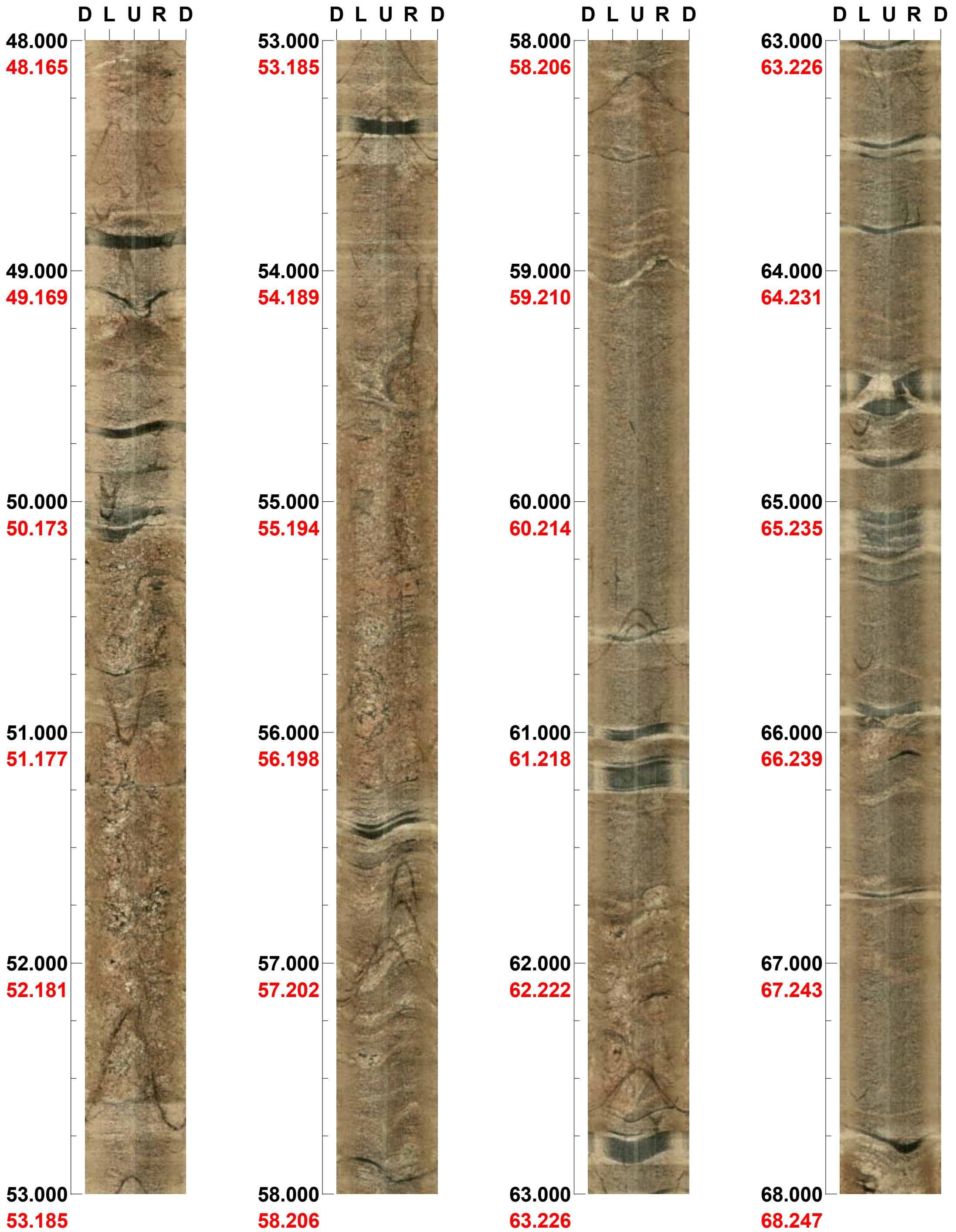
Depth range: 28.000 - 48.000 m



(2 / 9) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark
Bore hole No.: HFM18 Azimuth: 315 Inclination: -60

Depth range: 48.000 - 68.000 m



(3 / 9) Scale: 1/25 Aspect ratio: 100 %

Project name: Forsmark

Bore hole No.: HFM18 **Azimuth: 315** **Inclination: -60**

Depth range: 68.000 - 88.000 m

(4 / 9) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

Bore hole No.: HFM18 **Azimuth: 315** **Inclination: -60**

Depth range: 88.000 - 108.000 m

(5 / 9) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark
Bore hole No.: HFM18 Azimuth: 315 Inclination: -60

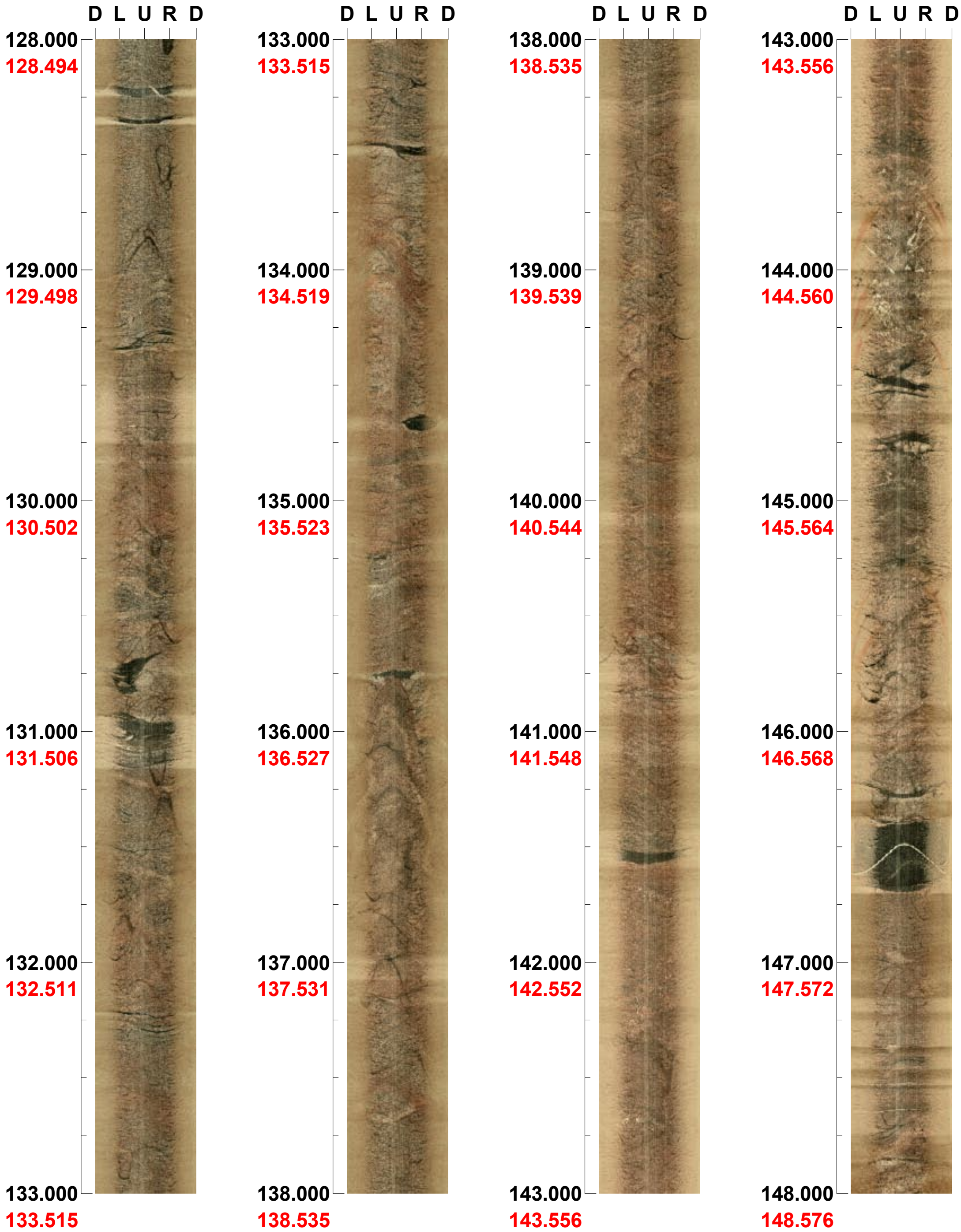
Depth range: 108.000 - 128.000 m

(6 / 9) Scale: 1/25 Aspect ratio: 100 %

Project name: Forsmark

Bore hole No.: HFM18 **Azimuth: 315** **Inclination: -60**

Depth range: 128.000 - 148.000 m



(7 / 9) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

Bore hole No.: HFM18 **Azimuth: 315** **Inclination: -60**

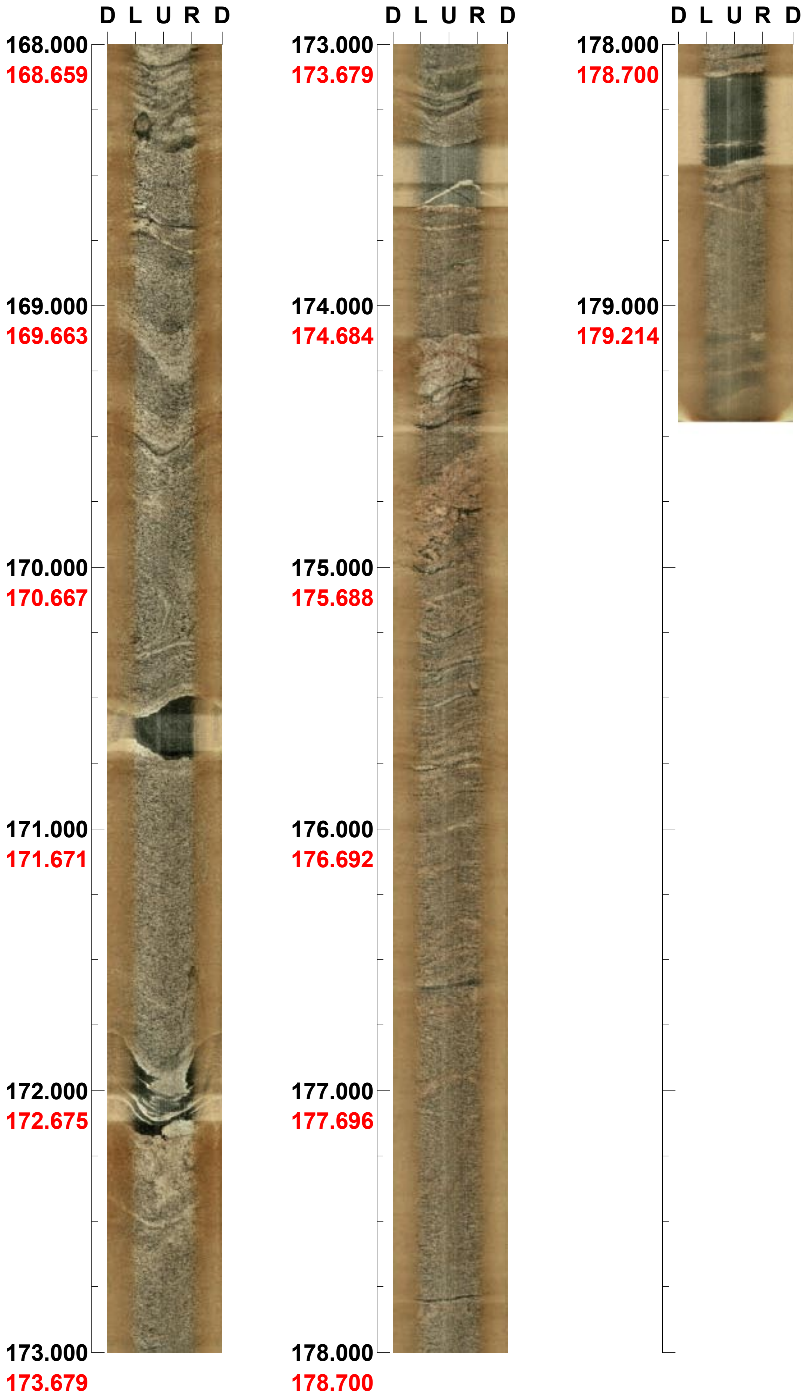
Depth range: 148.000 - 168.000 m

(8 / 9) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

Bore hole No.: HFM18 **Azimuth: 315** **Inclination: -60**

Depth range: 168.000 - 179.441 m



(9 / 9) **Scale: 1/25** **Aspect ratio: 100 %**

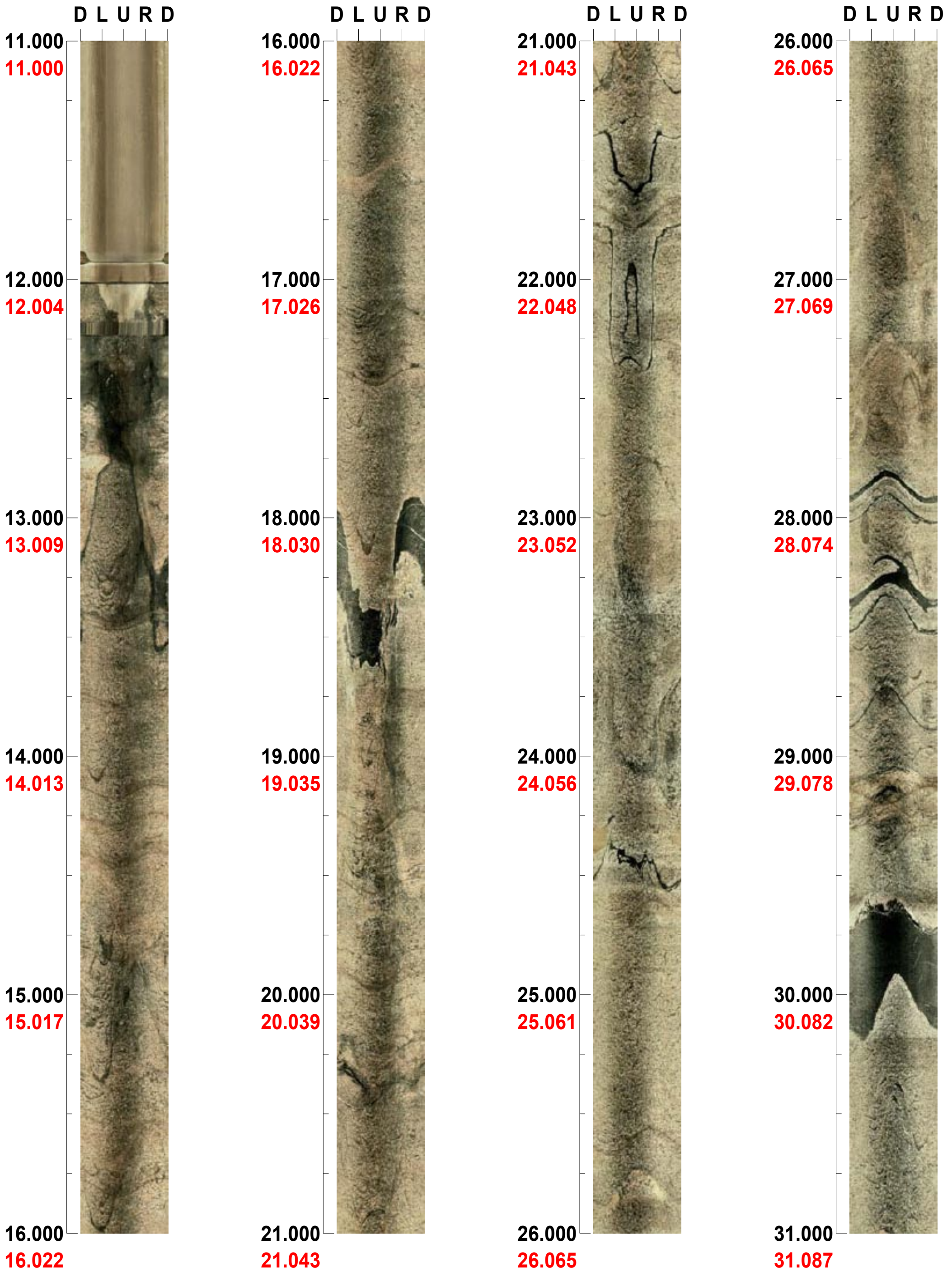
BIPS logging of HFM19, 11–184.6 m

Project name: Forsmark

Image file	: g:\skb\bips\forsmark\hfm19\omlev~ru\hfm19.bip
BDT file	: g:\skb\bips\forsmark\hfm19\omlev~ru\hfm19.bdt
Locality	: FORSMARK
Bore hole number	: HFM19
Date	: 04/05/10
Time	: 15:15:00
Depth range	: 11.000 - 184.643 m (red figures = corrected values)
Azimuth	: 280
Inclination	: -60
Diameter	: 140.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 90 %
Pages	: 9
Color	: +0 +0 +0

Project name: Forsmark
Bore hole No.: HFM19 **Azimuth: 280** **Inclination: -60**

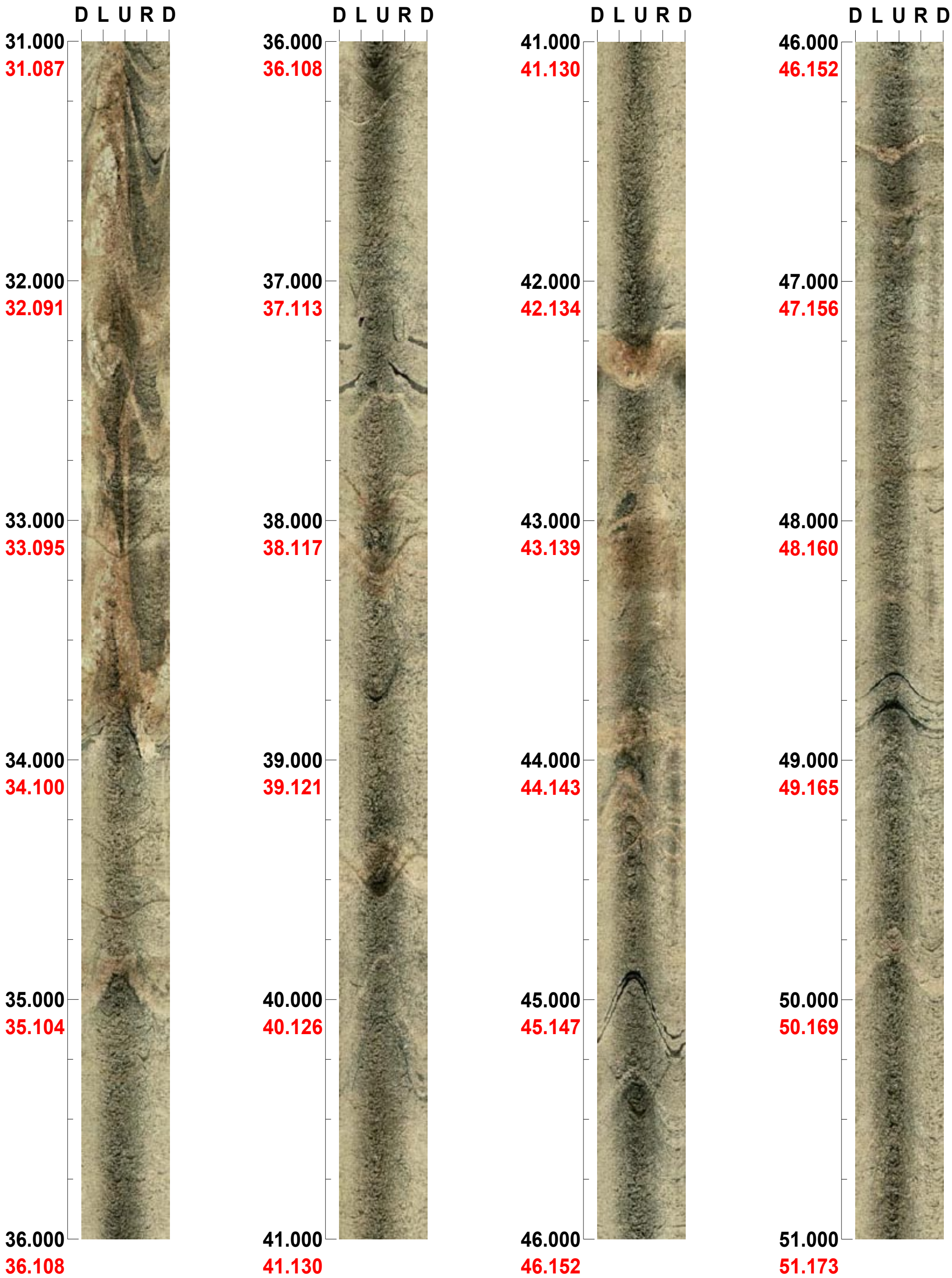
Depth range: 11.000 - 31.000 m



(1 / 9) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark
Bore hole No.: HFM19 **Azimuth: 280** **Inclination: -60**

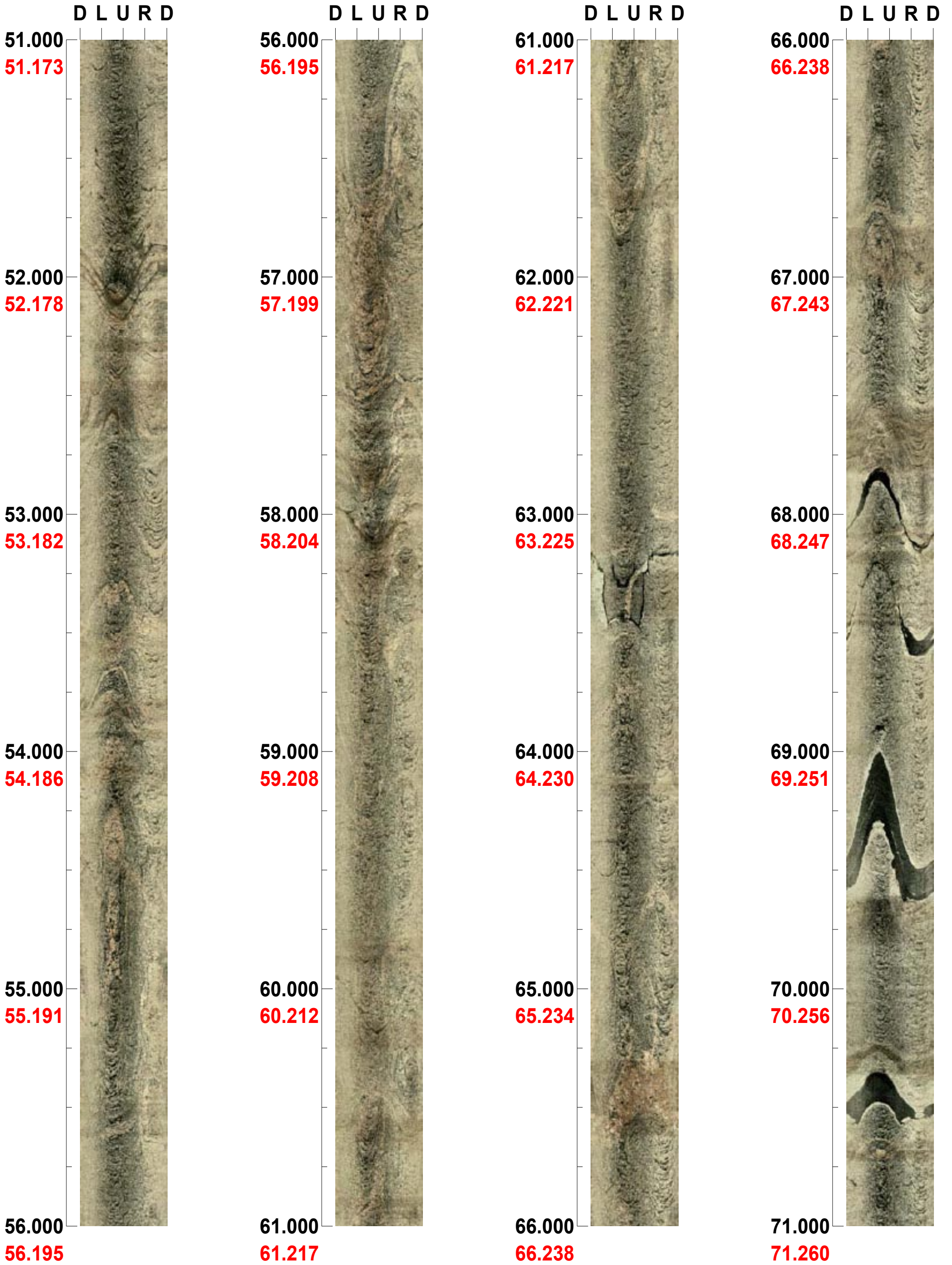
Depth range: 31.000 - 51.000 m



(2 / 9) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark
Bore hole No.: HFM19 **Azimuth: 280** **Inclination: -60**

Depth range: 51.000 - 71.000 m



(3 / 9) **Scale: 1/25** **Aspect ratio: 90 %**

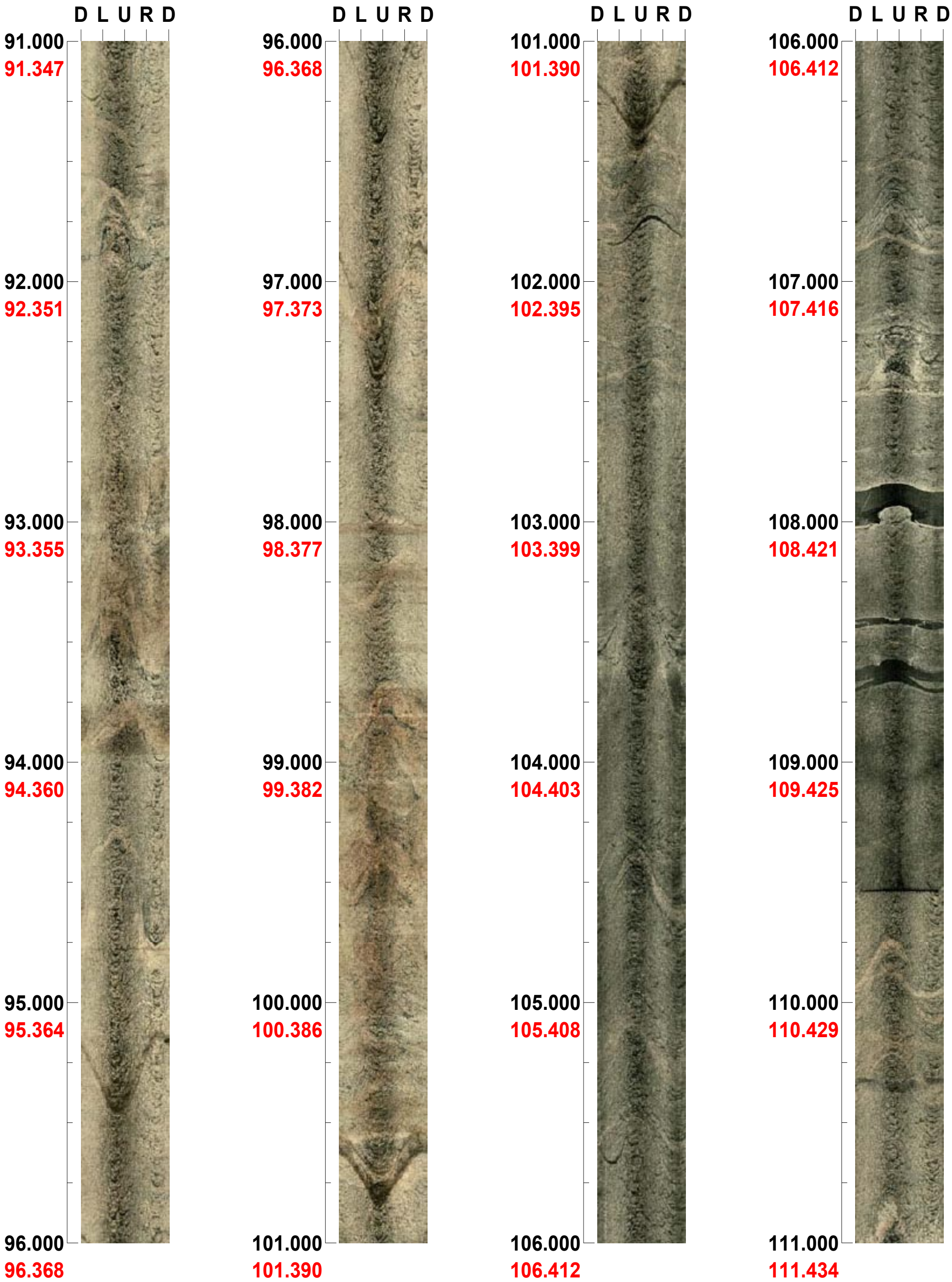
Project name: Forsmark
Bore hole No.: HFM19 **Azimuth: 280** **Inclination: -60**

Depth range: 71.000 - 91.000 m

(4 / 9) Scale: 1/25 Aspect ratio: 90 %

Project name: Forsmark
Bore hole No.: HFM19 Azimuth: 280 Inclination: -60

Depth range: 91.000 - 111.000 m

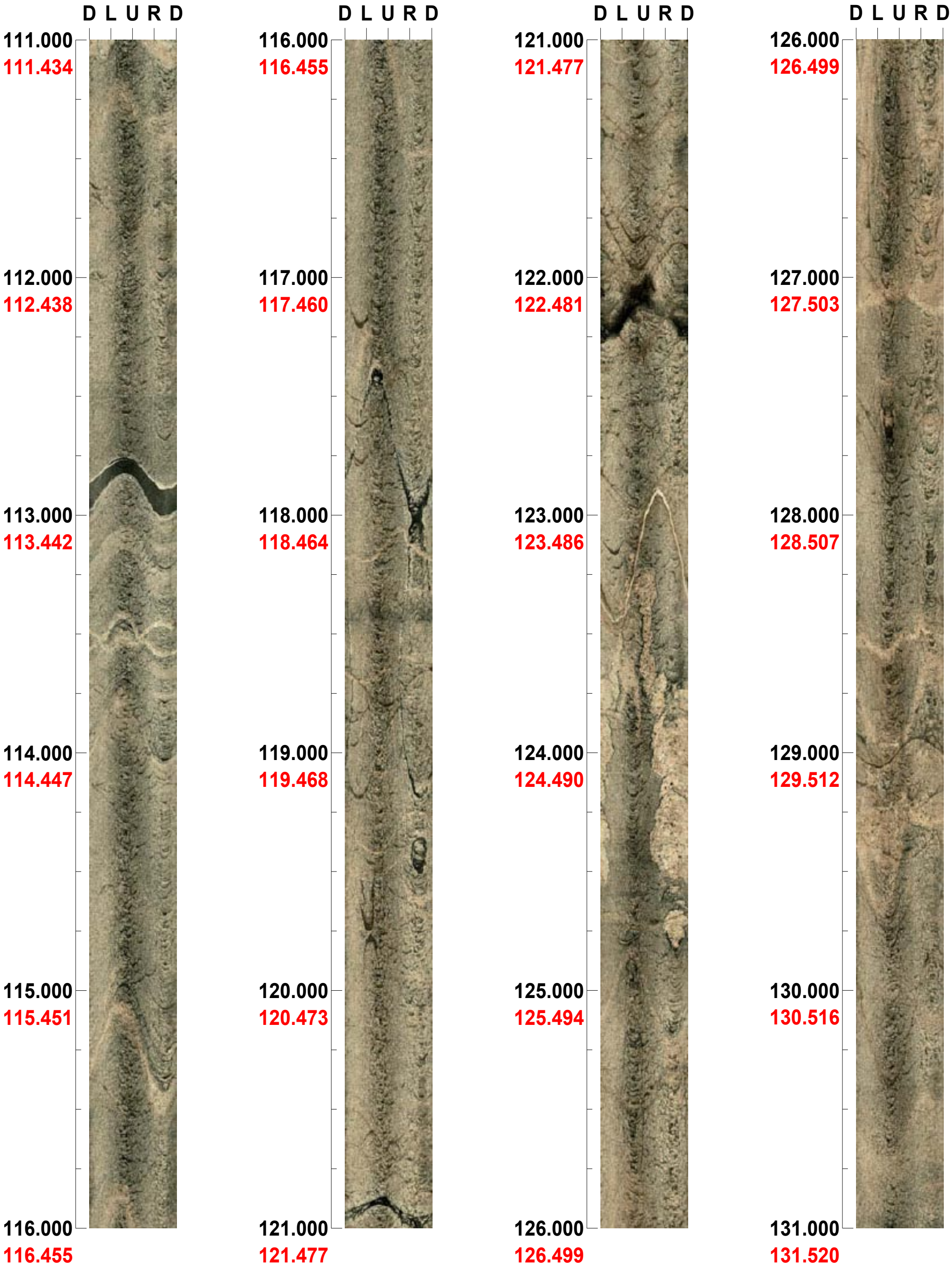


(5 / 9) Scale: 1/25 Aspect ratio: 90 %

Project name: Forsmark

Bore hole No.: HFM19 **Azimuth: 280** **Inclination: -60**

Depth range: 111.000 - 131.000 m



(6 / 9) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark

Bore hole No.: HFM19 **Azimuth: 280** **Inclination: -60**

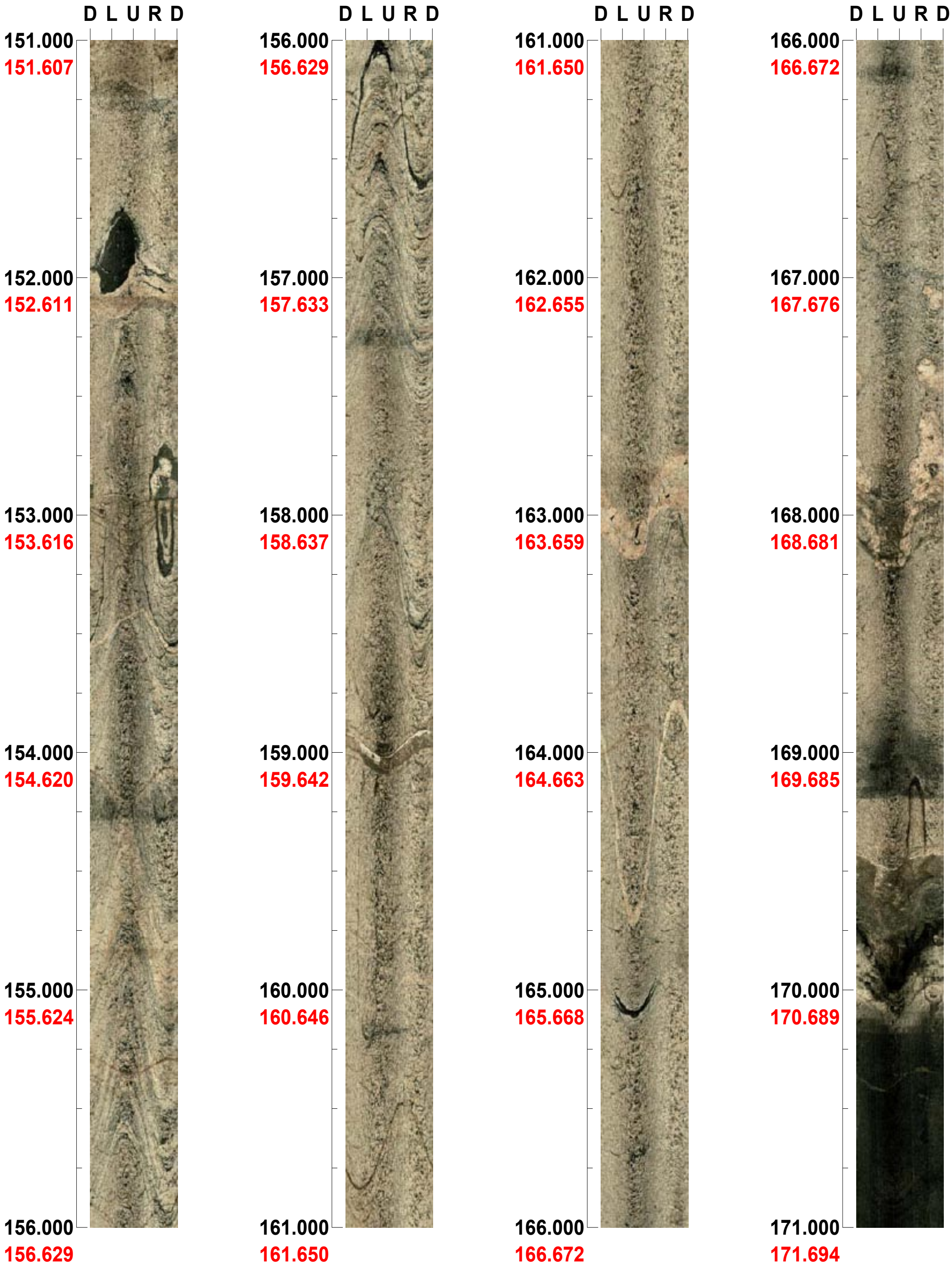
Depth range: 131.000 - 151.000 m

(7 / 9) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark

Bore hole No.: HFM19 **Azimuth: 280** **Inclination: -60**

Depth range: 151.000 - 171.000 m



(8 / 9) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark
Bore hole No.: HFM19 **Azimuth: 280** **Inclination: -60**

Depth range: 171.000 - 184.643 m

(9 / 9) **Scale: 1/25** **Aspect ratio: 90 %**

Appendix 11

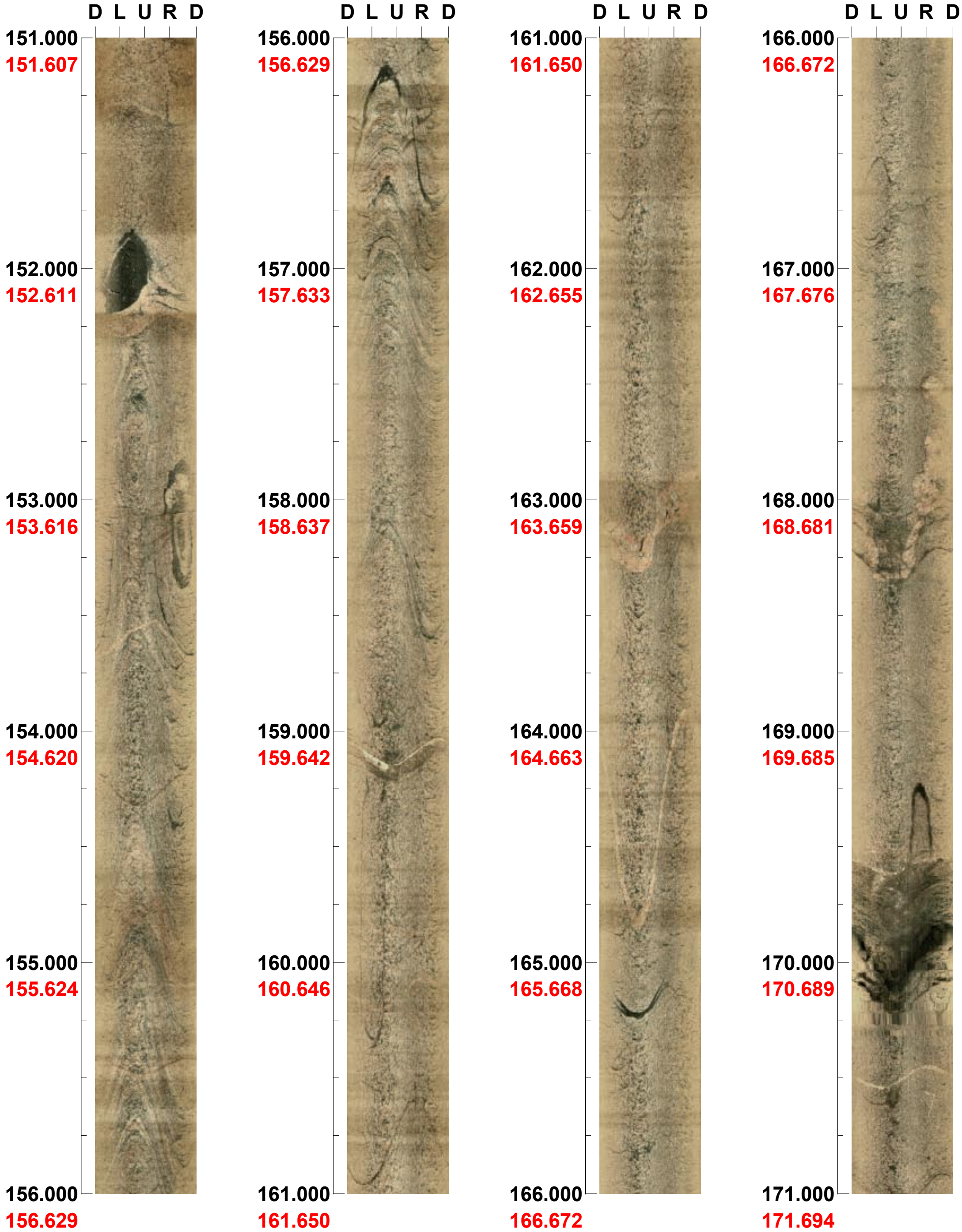
BIPS logging of HFM19, 151–184.4 m

Project name: Forsmark

Image file	: h:\work\hfm19\bips\hfm19.bip
BDT file	: h:\work\hfm19\bips\hfm19.bdt
Locality	: FORSMARK
Bore hole number	: HFM19
Date	: 04/01/16
Time	: 08:14:00
Depth range	: 151.000 - 184.408 m (red figures = corrected values)
Azimuth	: 280
Inclination	: -60
Diameter	: 140.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 100 %
Pages	: 9
Color	: +0 +0 +0

Project name: Forsmark
Bore hole No.: HFM19 **Azimuth: 280** **Inclination: -60**

Depth range: 151.000 - 171.000 m

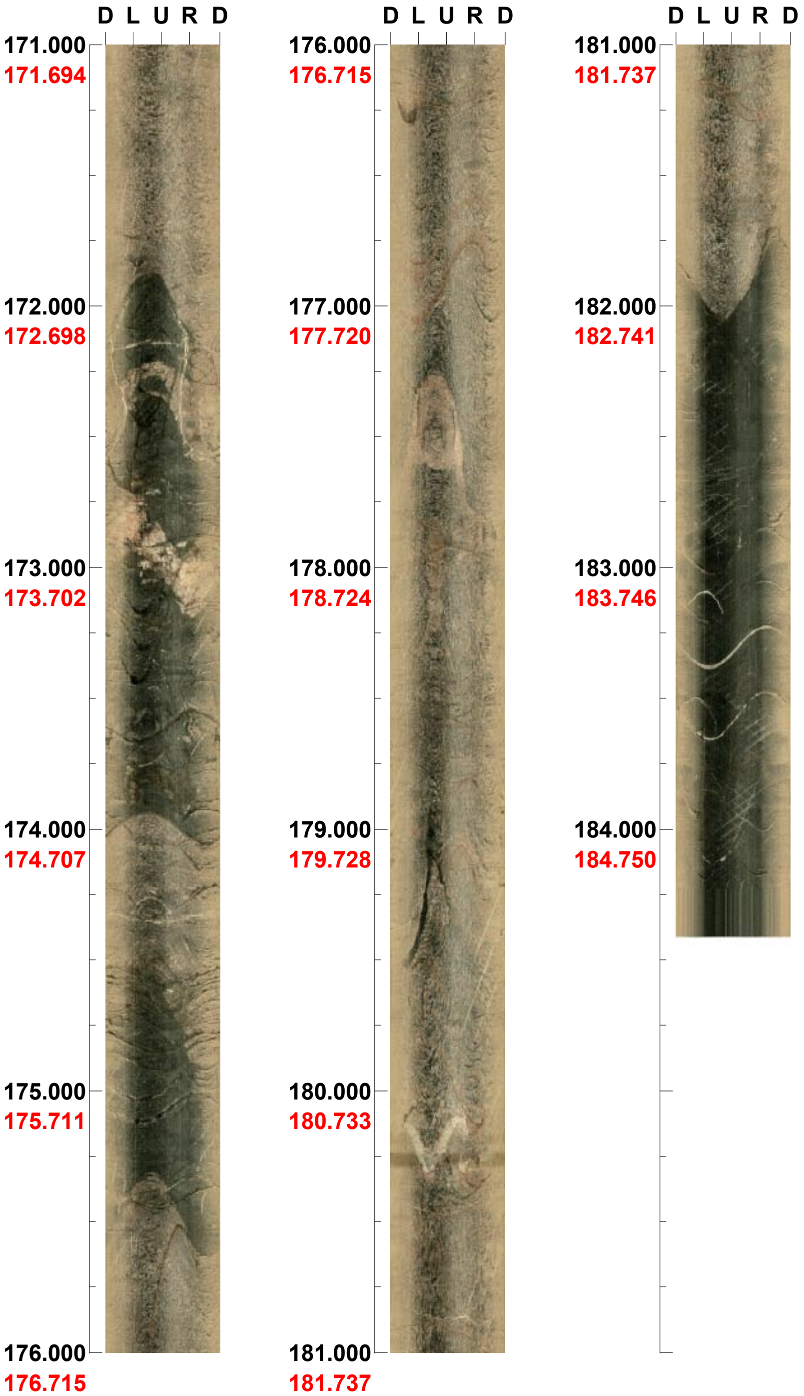


(8 / 9) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

Bore hole No.: HFM19 **Azimuth: 280** **Inclination: -60**

Depth range: 171.000 - 184.408 m



(9 / 9) **Scale: 1/25** **Aspect ratio: 100 %**