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Forsmark site investigation

RAMAC and BIPS logging in boreholes KFM07A (0–100 m), HFM20 and HFM21

Jaana Gustafsson, Christer Gustafsson
Malå Geoscience AB/RAYCON

April 2005

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Keywords: BIPS, RAMAC, Radar, TV, Forsmark, AP PF 400-04-92.

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 in the core drilled borehole KFM07A (0–100 m) and BIPS logging and borehole radar measurements (RAMAC) and in the percussion-drilled boreholes HFM20 and HFM21. All measurements were conducted by Malå Geoscience AB/RAYCON during June 2004.

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 HFM20 and HFM21 was relatively satisfying, but in some 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. 66 reflectors were identified in HFM20 and 49 reflectors in HFM21.

The BIPS images in KFM07A show reasonable possibilities for geological mapping and orientation of structures, thanks to high visibility of the borehole walls. The initial quality of the images from HFM20 and HFM21 were not satisfying due to low visibility in the water. They were remeasured with good quality in January 2005.

Sammanfattning

Denna rapport omfattar geofysiska loggningar inom platsundersökningsprogrammet för Forsmark. Mätningarna som presenteras här omfattar BIPS-loggning i KFM07A (0–100 m) och borrhålsradarmätningar (RAMAC) och BIPS-loggningar i borrhålen HFM20 och HFM21. Alla mätningar är utförda av Malå Geoscience AB/RAYCON under juni 2004.

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 HFM20 och HFM21 var relativt tillfredställande, men tidvis av sämre kvalité troligen till stor del beroende på en konduktiv miljö. En konduktiv miljö minskar möjligheterna att identifiera strukturer från borrhålsradardata. Dock har 66 radar-reflektorer identifierats i HFM20. Motsvarande antal för HFM21 är 49 stycken.

BIPS bilderna från KFM07A visar att förutsättningarna för geologisk kartering och spricks-orientering är goda tack vara bra visibilitet av borrhålsväggen. Bilderna från HFM20 och HFM21 var inte tillfredsställande på grund av dålig visibilitet i vattnet. BIPS mätningarna upprepades därför med bättre resultat i januari 2005.

Contents

1	**Introduction**	7
2	**Objective and scope**	9
3	**Equipment**	11
3.1	Radar measurements RAMAC	11
3.2	TV-Camera, BIPS	12
4	**Execution**	13
4.1	General	13
	4.1.1 RAMAC Radar	13
	4.1.2 BIPS	15
	4.1.3 Length measurements	16
4.2	Analyses and interpretation	16
	4.2.1 Radar	16
	4.2.2 BIPS	18
4.3	Nonconformities	18
5	**Results**	19
5.1	RAMAC logging	19
5.2	BIPS logging	24
	5.2.1 KFM07A	25
	5.2.2 HFM20	25
	5.2.3 HFM21	25
References		29
Appendix 1	Radar logging in HFM20, 0 to 298 m, dipole antennas 250, 100 and 20 MHz	31
Appendix 2	Radar logging in HFM21, 0 to 190 m, dipole antennas 250, 100 and 20 MHz	35
Appendix 3	BIPS logging in KFM07A, 9 to 100 m	37
Appendix 4	BIPS logging in HFM20, 12 to 297 m	43
Appendix 5	BIPS logging in HFM21, 12 to 202 m	59

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 TV-logging (BIPS) in the upper 100 m percussion drilled part of the otherwise core-drilled borehole KFM07A and borehole radar (RAMAC) and TV-logging (BIPS) in the percussion-drilled boreholes HFM20 and HFM21. The work was carried out in accordance with activity plan AP PF 400-04-92. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

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

Activity plan	Number	Version
Borrhålsradar och BIPS i KFM07A (0–100 m) samt HFM20 och HFM21	AP PF 400-04-92	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

This report includes measurements from 0 to approximately 100 m in borehole KFM07A. In HFM20 the loggings were performed to approximately 300 m depth, and in HFM21 to approximately 200 m depth. The percussion-drilled boreholes have a diameter of approximately 140 mm and the percussion drilled part of KFM07A (0–100 m) has a diameter of 250 mm.

All measurements were conducted by Malå Geoscience AB/RAYCON during June 2004. Figure 1-1 shows the borehole locations.

The used investigation techniques comprised:

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

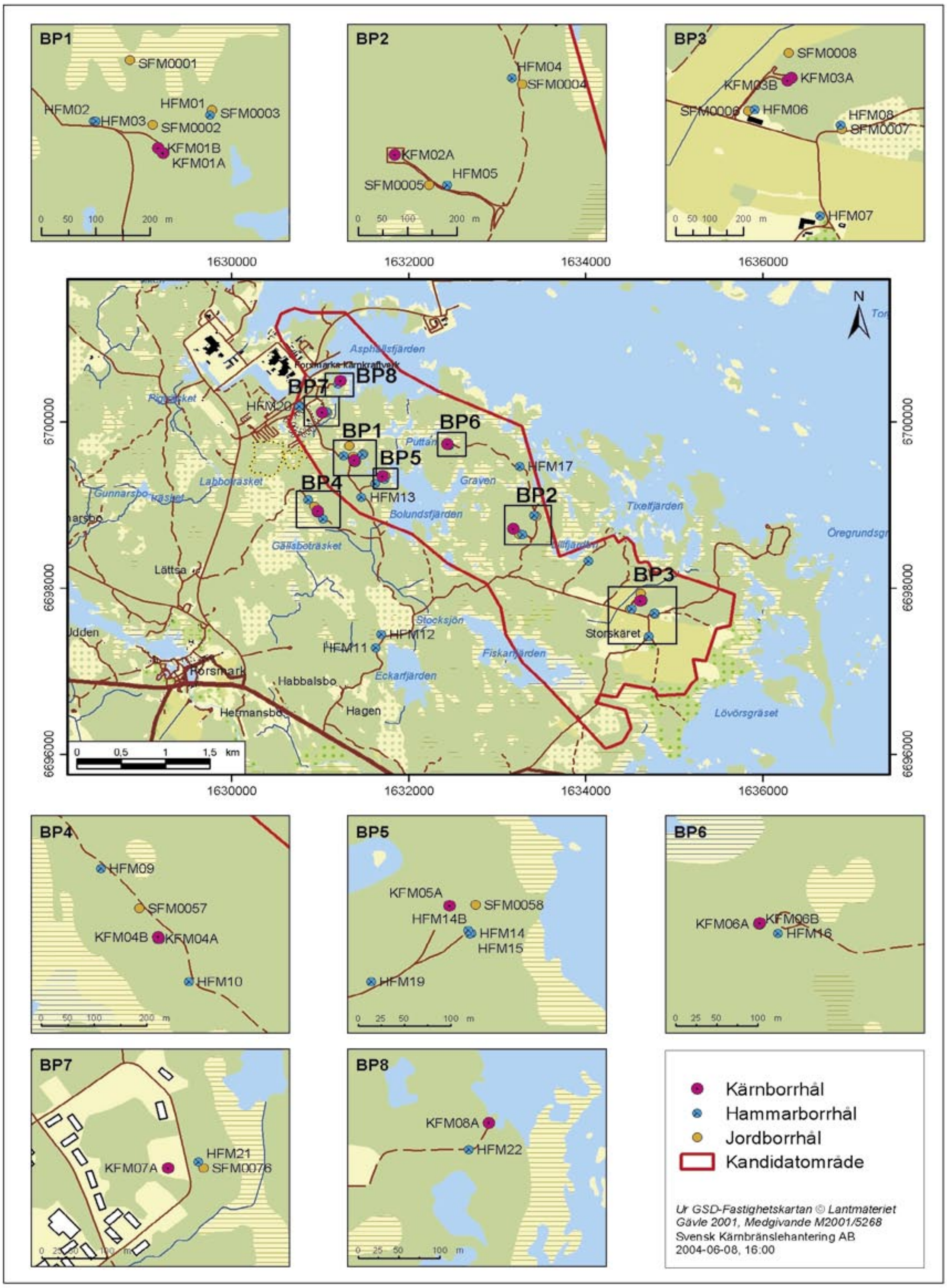


Figure 1-1. *General overview over the Forsmark area with the location of the boreholes KFM07A, HFM20 and HFM21. HFM20 is located outside the detailed map "BP7", see the big map.*

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.

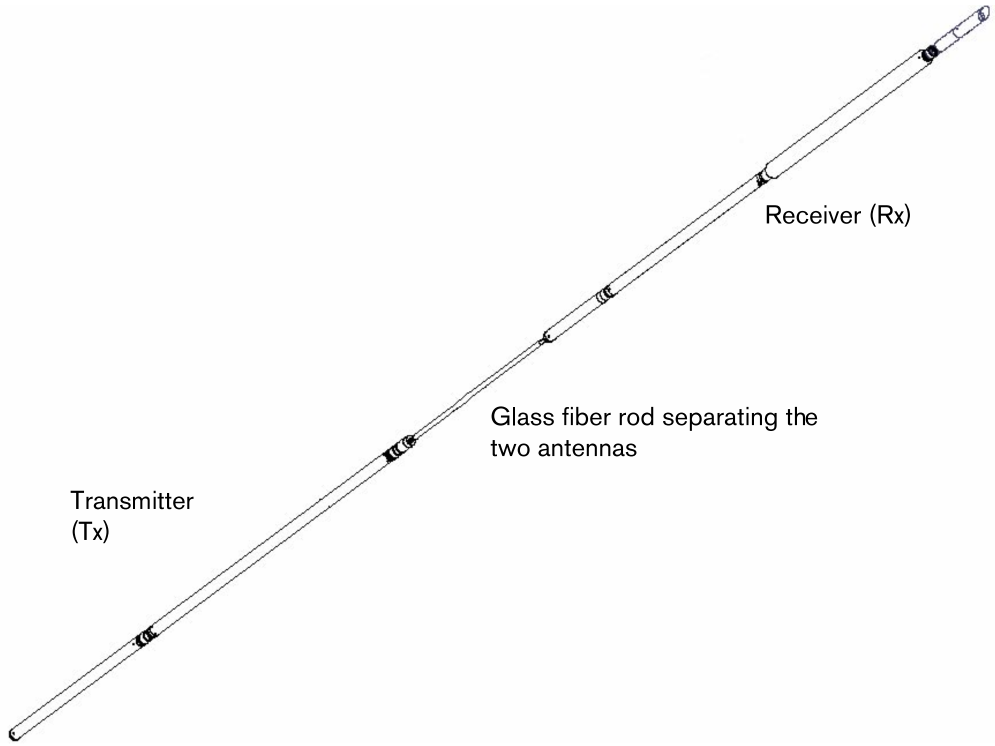


Figure 3-1. *Example of a borehole radar antenna.*

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, pixel circles are grabbed with a resolution of one pixel per degree.

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

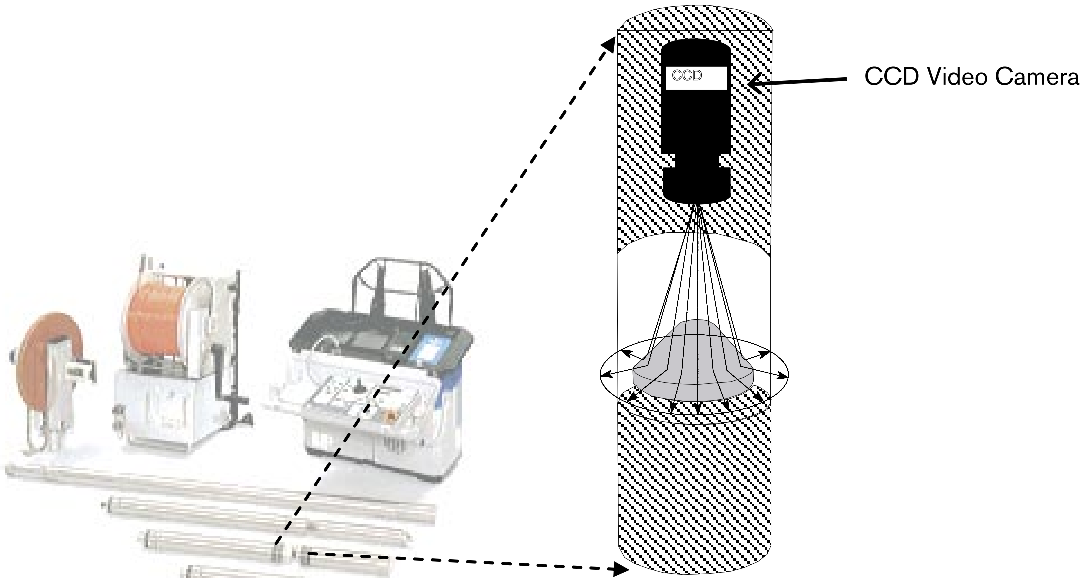


Figure 3-2. *An example of a BIP-system. To the right a sketch showing the principles of the conical mirror.*

4 Execution

4.1 General

4.1.1 RAMAC Radar

The measurements in HFM20 and HFM21 were carried out with dipole radar antennas, with frequencies of 250, 100 and 20 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 separation between the transmitter and receiver antennas are kept fixed by glass fiber rods according to Table 4-1 and 4-2. 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). Before the logging operation, the antennas and cable were cleaned according to the internal document SKB MD 600.004.

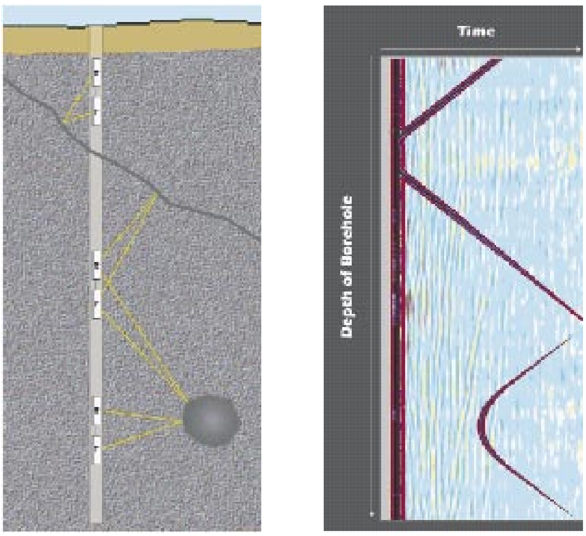


Figure 4-1. *The principle of radar borehole reflection survey (left) and an example of result (right).*

For more information on system settings used in the investigation of HFM20 and HFM21, see Table 4-1 and 4-2 below.

Table 4-1. Radar logging information from HFM20.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**HFM20**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Operator:	**CG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
Logging date:		04-06-15	04-06-15	04-06-15
Reference:		T.O.C.	T.O.C.	T.O.C.
Sampling frequency (MHz):		619	951	257
Number of samples:		2,588	518	512
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):		299.5	297.7	295.7
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 HFM21.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**HFM21**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Operator:	**CG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
Logging date:		04-06-14	04-06-14	04-06-14
Reference:		T.O.C.	T.O.C.	T.O.C.
Sampling frequency (MHz):		619	518	518
Number of samples:		2,588	951	257
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):		196.5	199.6	195.1
Trace interval (m):		0.1	0.2	0.25
Antenna separation (m):		2.4	3.9	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 pixel circle 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 logging with the SKB BIPS in KFM07A. No test measurements were performed for HFM20 and HFM21 because the use of the BIPS 4 system. That system cannot handle the test pipe and is not calibrated for the measuring wheel attached to the pipe. 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 for every single borehole presented in Appendix 3 to 5 in this report.

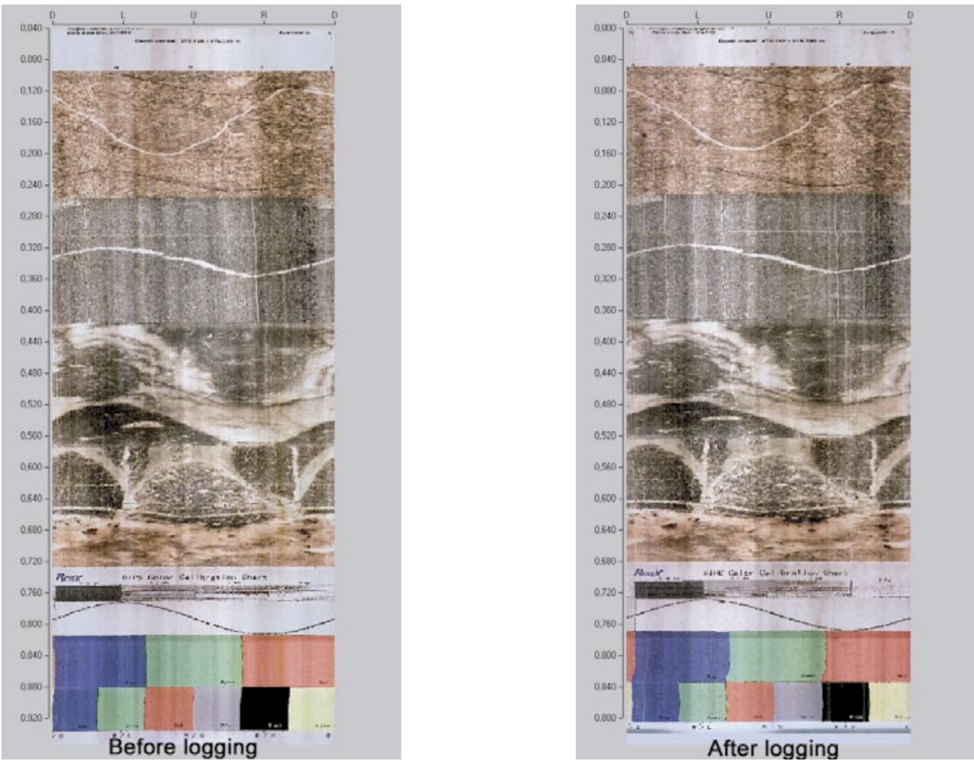


Figure 4-2. *Results from logging in the test pipe before and after the logging campaign in June with the SKB BIPS equipment.*

4.1.3 Length measurements

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

During the BIPS logging in core-drilled boreholes, were the reference marks in the borehole wall is visible on the image, the logging cable is marked with scotch tape. These tape marks are then used for controlling the RAMAC and BIPS measurements in percussion-drilled boreholes. The depth marks (presented in the Appendix 3 to 5) in the BIPS images represent the recorded depth (in black) and adjusted depth (in red).

The experience we have from earlier measurements with dipole antennas in the 1,000 m long core-drilled boreholes in Forsmark and Oskarshamn for the radar logging is that the depth divergence is less than 50 cm in the deepest parts of the boreholes.

As all the measured boreholes in this case are less than 300 m, the depth divergence is only about 20 cm in the deepest parts of the boreholes.

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 (metres per microsecond) /1/. The velocity measurement was performed with the 100 MHz antenna.

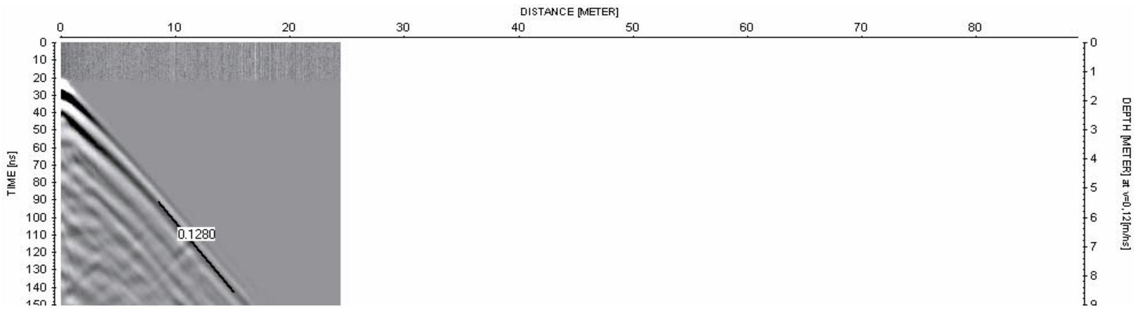


Figure 4-3. Results from velocity measurements in HFM03.

The visualization of data in Appendix 1 and 2 is made with ReflexWin, a Windows based processing software for filtering and analysis of borehole radar data. The processing steps for the data presented in Appendix 1 and 2 are given in Tables 4-3 and 4-4. 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.

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 the Tables 5-1 and 5-2 and are also visible on the radargrams in Appendix 1 and 2.

Table 4-3. Processing steps for borehole radar data from HFM20.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**HFM20**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JA**	**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 4-4. Processing steps for borehole radar data from HFM21.

Site:	**Forsmark**	**Logging company:**	**RAYCON**	
BH:	**HFM21**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JA**	**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

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 PDPP from RaaX was used.

4.3 Nonconformities

The initial BIPS images from HFM20 and HFM21 were not satisfying. Therefore the holes were remeasured in January 2005.

5 Results

The results from the BIPS measurements in KFM07A, HFM20 and HFM21 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 HFM20 and HFM21 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 5-4. Radar data are also visualized in Appendix 1 and 2. It should be remembered that the images in Appendix 1 and 2 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 also exist, as several parallel structures seen in the 100 MHz data from HFM20. 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.

The data quality from HFM20 and HFM21, (as seen in Appendix 1 and 2) 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 conductive environment of course also reduces the possibility to distinguish and interpret possibly structures in the rock which otherwise could give a reflection. An example of this is seen in data from HFM20 from approximately 175 to 240 m depth, where a number of structures can be seen, but not clearly enough for interpretation.

As also seen in Appendix 1 and 2 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 concluded that the structure is quite significant.

In Tables 5-1 and 5-2 below the distribution of identified structures along the borehole are listed HFM20 and HFM21.

Table 5-1. Identified structures as a function of depth in HFM20.

Depth (m)	No of structures
–0	4
0–20	1
20–40	10
40–60	2
60–80	3
80–100	4
100–120	6
120–140	5
140–160	5
160–180	2
180–200	3
200–220	–
220–240	4
240–260	5
260–280	5
280–300	6
300–	1

Table 5-2. Identified structures as a function of depth in HFM21.

Depth (m)	No of structures
20–40	5
40–60	5
60–80	3
80–100	4
100–120	7
120–140	6
140–160	5
160–180	9
180–200	4
200–	1

Tables 5-3 and 5-4 summarises the interpretation of radar data from HFM20 and HFM21. In the tables the depth and intersection angle to the identified structures are listed.

Table 5-3. Interpretation of radar reflectors from dipole antennas 20, 100 and 250 MHz borehole HFM20.

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas)			
Site:		**Forsmark**	
Borehole name:		**HFM20**	
Nominal velocity (m/μs):		**128.00**	
Object type	**Name**	**Intersection depth**	**Intersection angle**
PLANE	21	–388	4
PLANE	Dx	–56	5
PLANE	2	–33	3
PLANE	Ax	–31	28
PLANE	24	2.6	10
PLANE	A	23.5	74
PLANE	B	24.8	73
PLANE	Bx	26.3	90
PLANE	C	27.7	75
PLANE	D	32.2	17
PLANE	E	32.3	90
PLANE	F	34.4	74
PLANE	G	36.4	66
PLANE	Dxxx	37.6	14
PLANE	H	39.9	62
PLANE	I	51.6	75
PLANE	J	53.9	72
PLANE	Dxx	62.7	16
PLANE	K	63.9	66
PLANE	L	78	85
PLANE	Lx	81.7	66
PLANE	S	81.9	9
PLANE	M	86.6	80
PLANE	O	95.3	69
PLANE	P	100.1	71
PLANE	N	100.3	30
PLANE	Sx	104.1	16
PLANE	Q	105.8	76
PLANE	Nx	110.7	40
PLANE	R	118.7	66
PLANE	1	122.9	7
PLANE	Rx	123.5	72
PLANE	T	127.5	68
PLANE	Tx	130	70
PLANE	U	137.6	90
PLANE	3	143.9	10
PLANE	V	146.5	63
PLANE	22	154.5	17
PLANE	15x	156.7	3
PLANE	W	159.8	10
PLANE	X	167.9	64

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas)			
Site:	**Forsmark**		
Borehole name:	**HFM20**		
Nominal velocity (m/µs):	**128.00**		
Object type	**Name**	**Intersection depth**	**Intersection angle**
PLANE	4	175.6	72
PLANE	Y	181.2	16
PLANE	6	194.8	23
PLANE	5	197.3	65
PLANE	Z	238.7	9
PLANE	9	236.3	36
PLANE	8	238.4	22
PLANE	9xx	239.8	60
PLANE	10	248.9	62
PLANE	7	251.4	16
PLANE	11	255.2	63
PLANE	9xx	255.9	27
PLANE	12	257.3	19
PLANE	13	263.8	76
PLANE	15	268.6	16
PLANE	23	269.6	15
PLANE	14	271.6	62
PLANE	14x	276.9	60
PLANE	17	281.3	58
PLANE	17x	282.3	52
PLANE	18	284.1	20
PLANE	16	285.8	63
PLANE	19	289.8	62
PLANE	19x	288.2	60
PLANE	20	302.3	73

Table 5-4. Interpretation of radar reflectors from dipole antennas 20, 100 and 250 MHz in borehole HFM21.

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas)			
Site: Forsmark			
Borehole name: HFM21			
Nominal velocity (m/µs): 128.00			
Object type	**Name**	**Intersection depth**	**Intersection angle**
PLANE	A	20.7	64
PLANE	B	24	64
PLANE	C	27.7	68
PLANE	D	31.6	64
PLANE	E	37.6	56
PLANE	F	42.9	51
PLANE	Fx	44.8	59

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas)			
Site: Forsmark **Borehole name: HFM21** **Nominal velocity (m/μs): 128.00**			
Object type	**Name**	**Intersection depth**	**Intersection angle**
PLANE	G	48.5	54
PLANE	H	54.4	53
PLANE	I	56.9	59
PLANE	J	67.2	57
PLANE	K	71.6	63
PLANE	L	79.4	41
PLANE	M	83.2	46
PLANE	N	91.5	61
PLANE	O	95.2	51
PLANE	P	97.4	65
PLANE	Q	102.6	45
PLANE	R	106.8	42
PLANE	S	108.5	47
PLANE	Tx	109.3	32
PLANE	T	109.6	71
PLANE	U	112.8	58
PLANE	V	118	47
PLANE	W	120.9	37
PLANE	X	123.7	59
PLANE	Xx	123.9	40
PLANE	1	132.4	47
PLANE	1x	132.6	70
PLANE	1xx	132.8	38
PLANE	2	140.1	65
PLANE	3x	146.2	73
PLANE	3	148.5	40
PLANE	4	151.1	39
PLANE	5	157.7	39
PLANE	6	162.3	34
PLANE	7	164.8	34
PLANE	7x	165.9	53
PLANE	8x	167.6	48
PLANE	8	168.1	41
PLANE	9	171.7	42
PLANE	10	174.7	42
PLANE	10x	176.6	61
PLANE	11	178.6	39
PLANE	12	182.3	44
PLANE	13	186.8	38
PLANE	14x	197	49
PLANE	14	198.8	42
PLANE	15	250.6	29

In Appendix 1 and 2, 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 Tables 5-5 and 5-6.

Table 5-5. Decrease in amplitude for the 250 MHz antenna for borehole HFM20.

Depth (m)
20–30
35–40
55–65
75
80–90
105
115–135
140–150
165–170
175
250
285–290

Table 5-6. Decrease in amplitude for the 250 MHz antenna for borehole HFM21.

Depth (m)
25–30
45–55
95–105
120
170

5.2 BIPS logging

The BIPS pictures are presented in Appendix 3 to 5.

To get the best possible depth accuracy, the BIPS images are adjusted to the reference marks on the logging cable. Additionally the marks on the borehole wall created by the drill rig in core drilled boreholes are visible on the BIPS screen. The recorded length is adjusted to these visible marks. In percussion drilled boreholes we use these marks on the cable as reference for the depth adjustment. The experience from logging in many boreholes is that the marks on the logging cable is very good and differs very little compared with the results from core-drilled boreholes. At present we have marks at 110, 150 and 200 meter on the logging cable that are used for depth adjustments of the BIPS results in percussion drilled boreholes.

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 Figures 4-2 and 4-3 in this report.

Data for the inclination and azimuth presented in this report for the boreholes are only preliminary (reference from AP PF 400-04-92).

5.2.1 KFM07A

Water quality is of good quality. The result is influenced by the big borehole diameter, 250 mm and the effect of to small centralisers, 165 mm. The manufacturer recommends the use of the camera up to 200 mm. Bigger borehole diameters will absorb to much of the light specially when the rock is dark. Figure 5-1 shows that it easier for the camera to control the iris function in parts of the borehole that have a lighter background colour.

5.2.2 HFM20

Figure 5-2 illustrates the image quality from the two measurements. At the second measurement the image quality was satisfying along the whole borehole length.

5.2.3 HFM21

At the second measurement the image quality was satisfying along the whole borehole length.

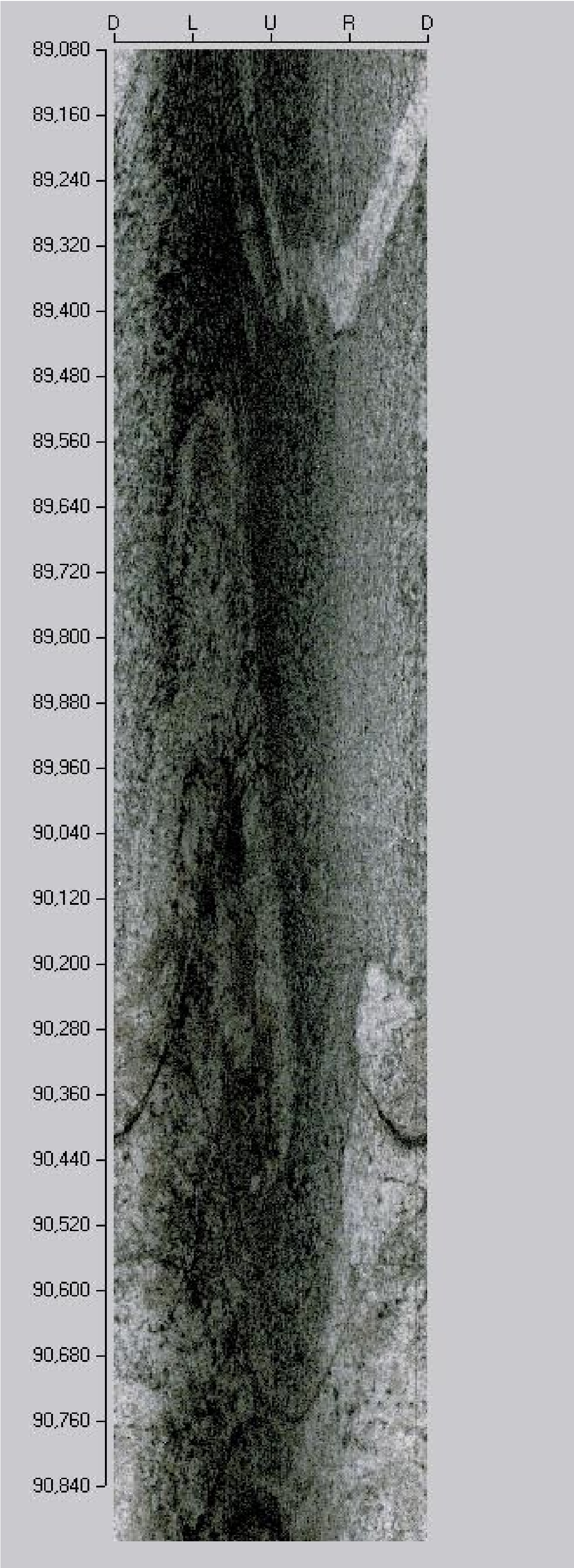


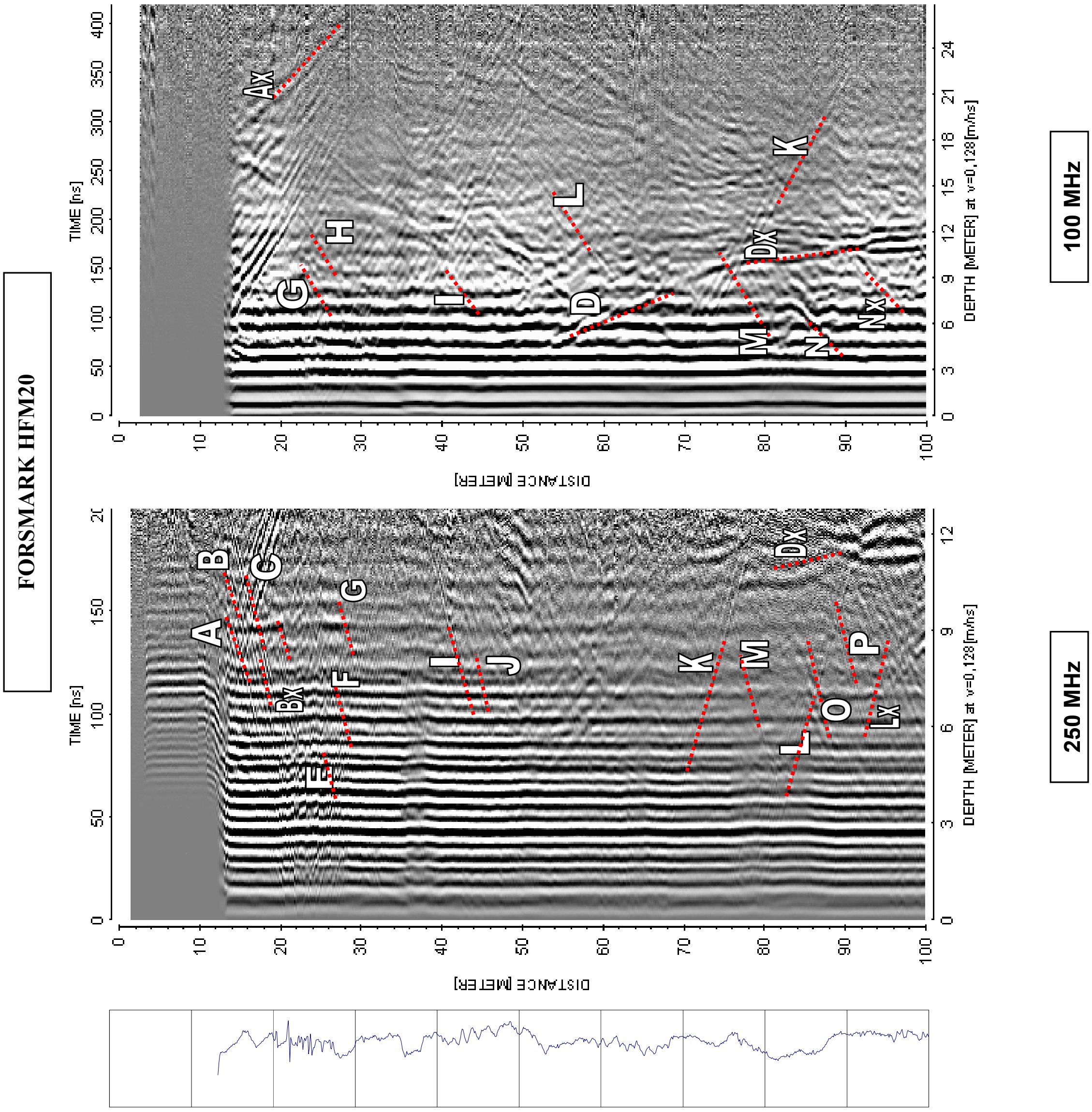
Figure 5-1. *Images affected by big borehole diameters and lack of light*

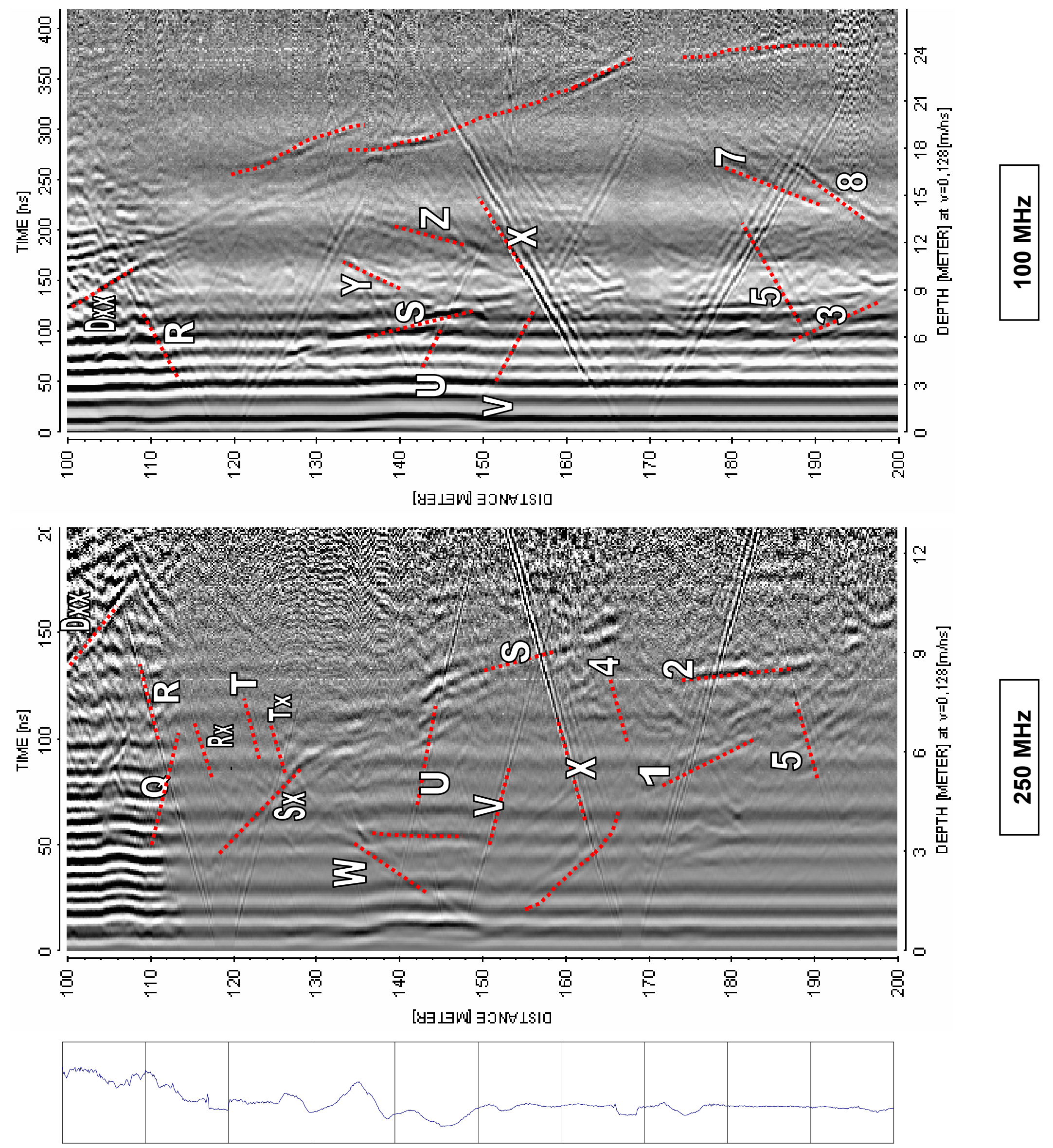
Figure 5-2. *BIPS Images (left from June 2004, right from January 2005) from a 1 m section around 26 meter illustrating the improved quality between the two measurements.*

References

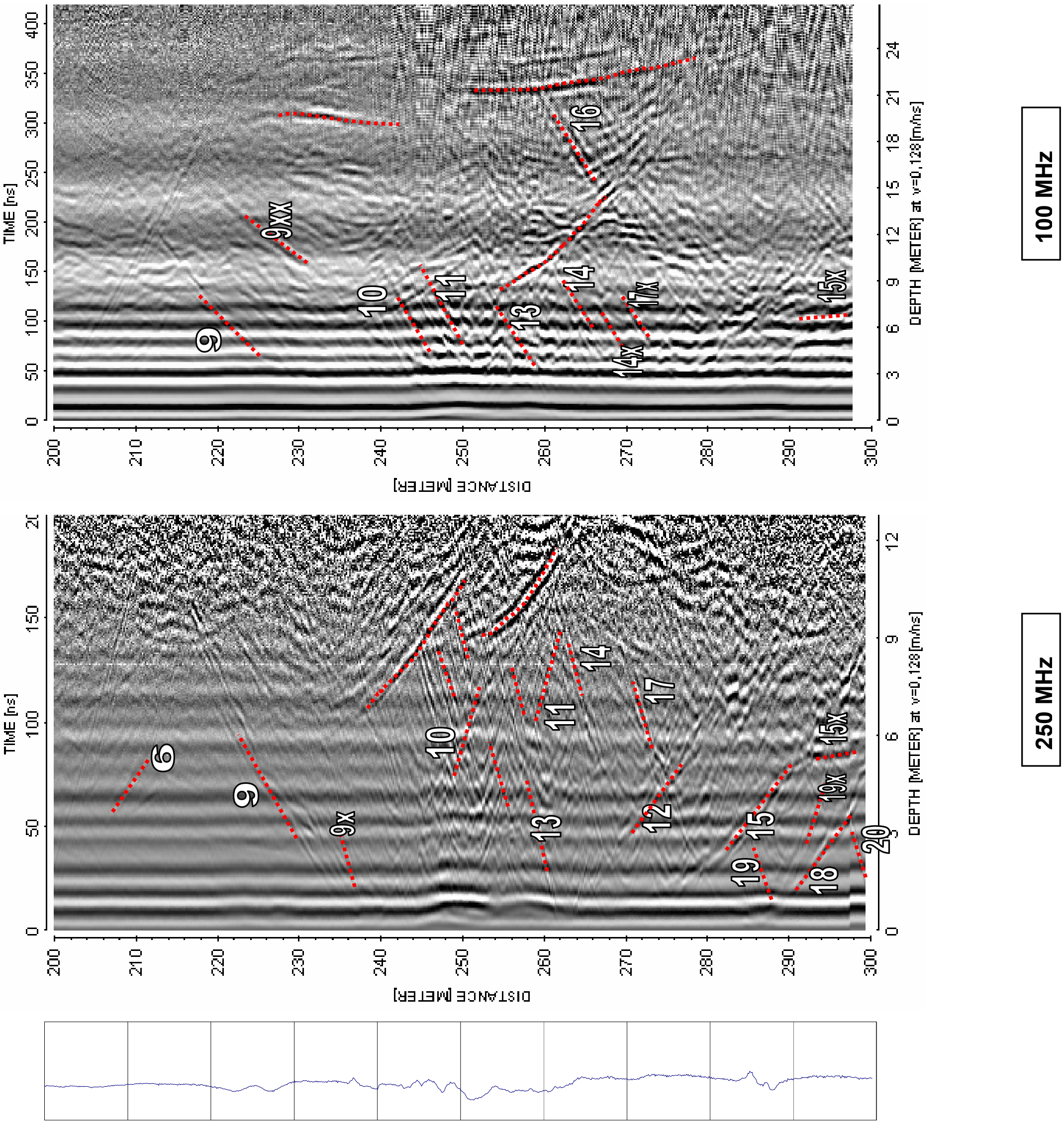
/1/ **Gustafsson C, Nilsson P, 2003.** Geophysical Radar and BIPS logging in borehole HFM01, HFM02, HFM03 and the percussion drilled part of KFM01A. SKB P-03-39. Svensk Kärnbränslehantering AB.

Radar logging in HFM20, 0 to 298 m, dipole antennas 250, 100 and 20 MHz

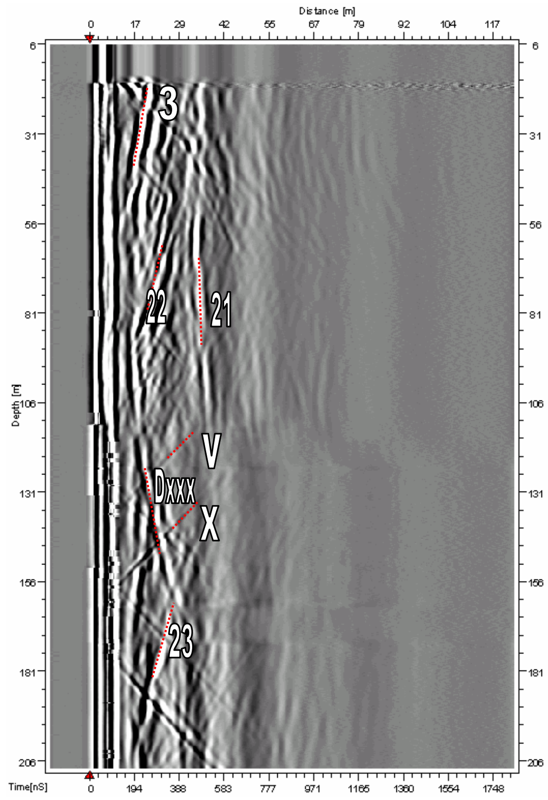


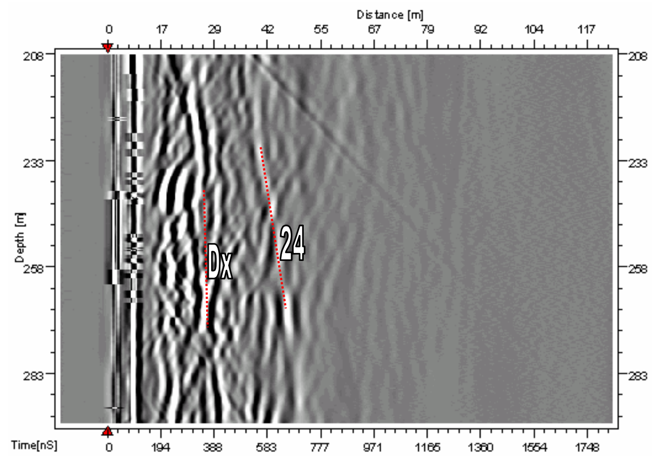

FORSMARK HFM20
100 MHz
250 MHz
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128 [m/ns]

FORSMARK HFM20

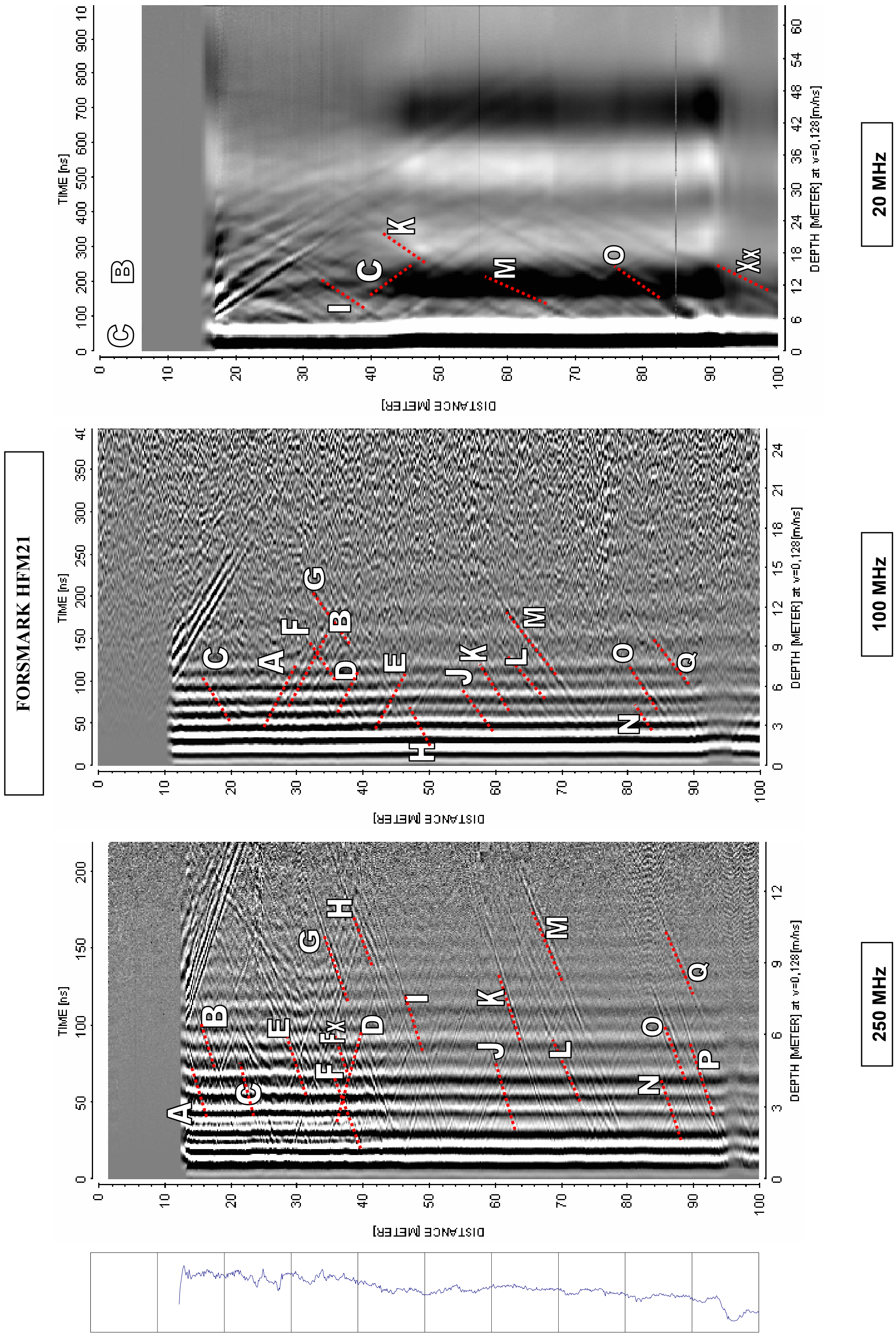


Forsmark HFM20 20MHz with interpretation

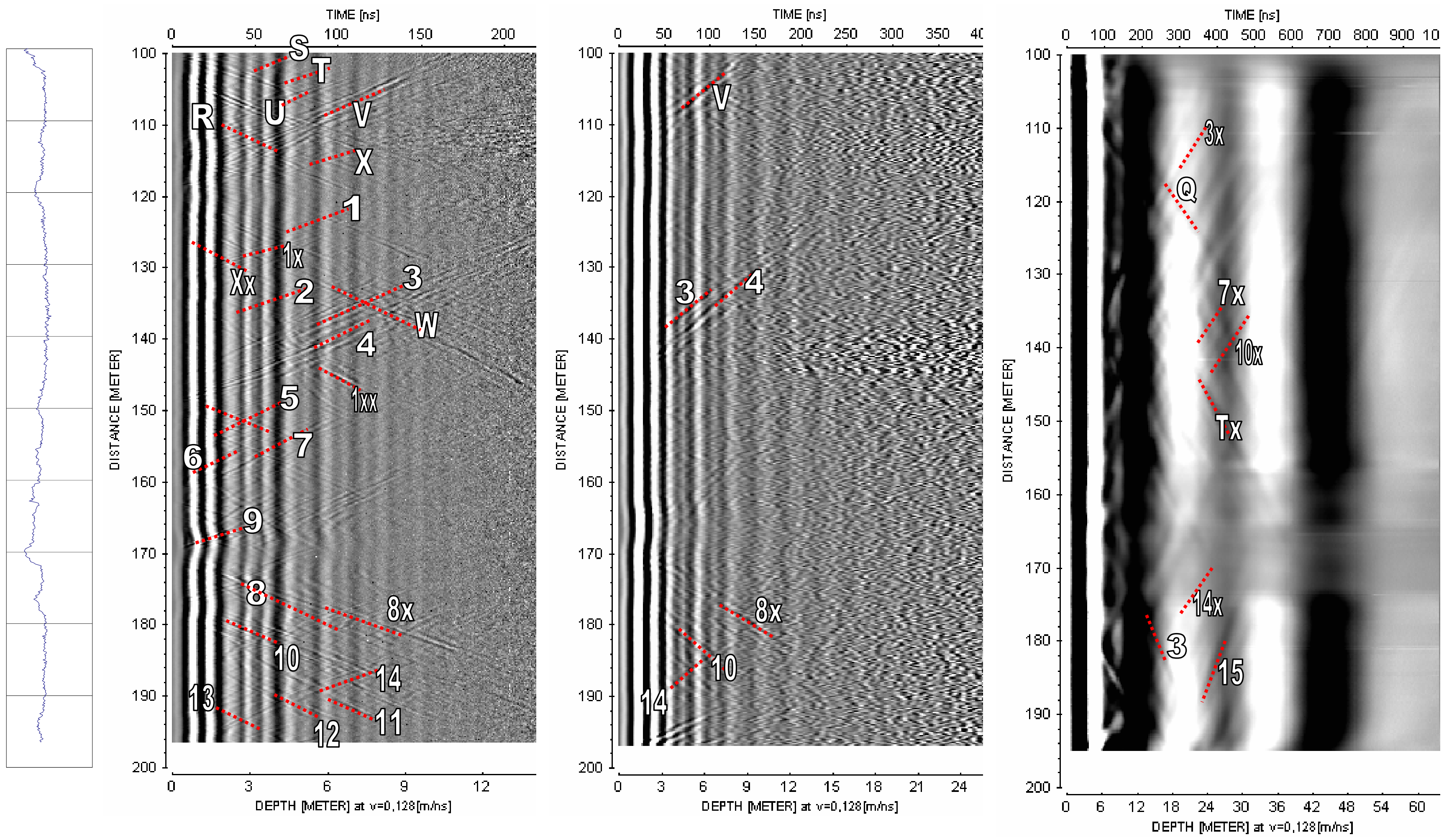




Radar logging in HFM21, 0 to 190 m, dipole antennas 250, 100 and 20 MHz



FORSMARK HFM21



250 MHz

100 MHz

20 MHz

BIPS logging in KFM07A, 9 to 100 m

Project name: Forsmark

Image file	: c:\work\r53__f~1\kfm07a\bips\kfm07a.bip
BDT file	: c:\work\r53__f~1\kfm07a\bips\kfm07a.bdt
Locality	: FORSMARK
Bore hole number	: KFM07A
Date	: 04/06/14
Time	: 09:26:00
Depth range	: 9.000 - 99.806 m
Azimuth	: 260
Inclination	: 60
Diameter	: 250.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 50 %
Pages	: 5
Color	: +0 +0 +0

Project name: Forsmark
Bore hole No.: KFM07A **Azimuth: 260** **Inclination: 60**

Depth range: 9.000 - 29.000 m

(1 / 5) **Scale: 1/25** **Aspect ratio: 50 %**

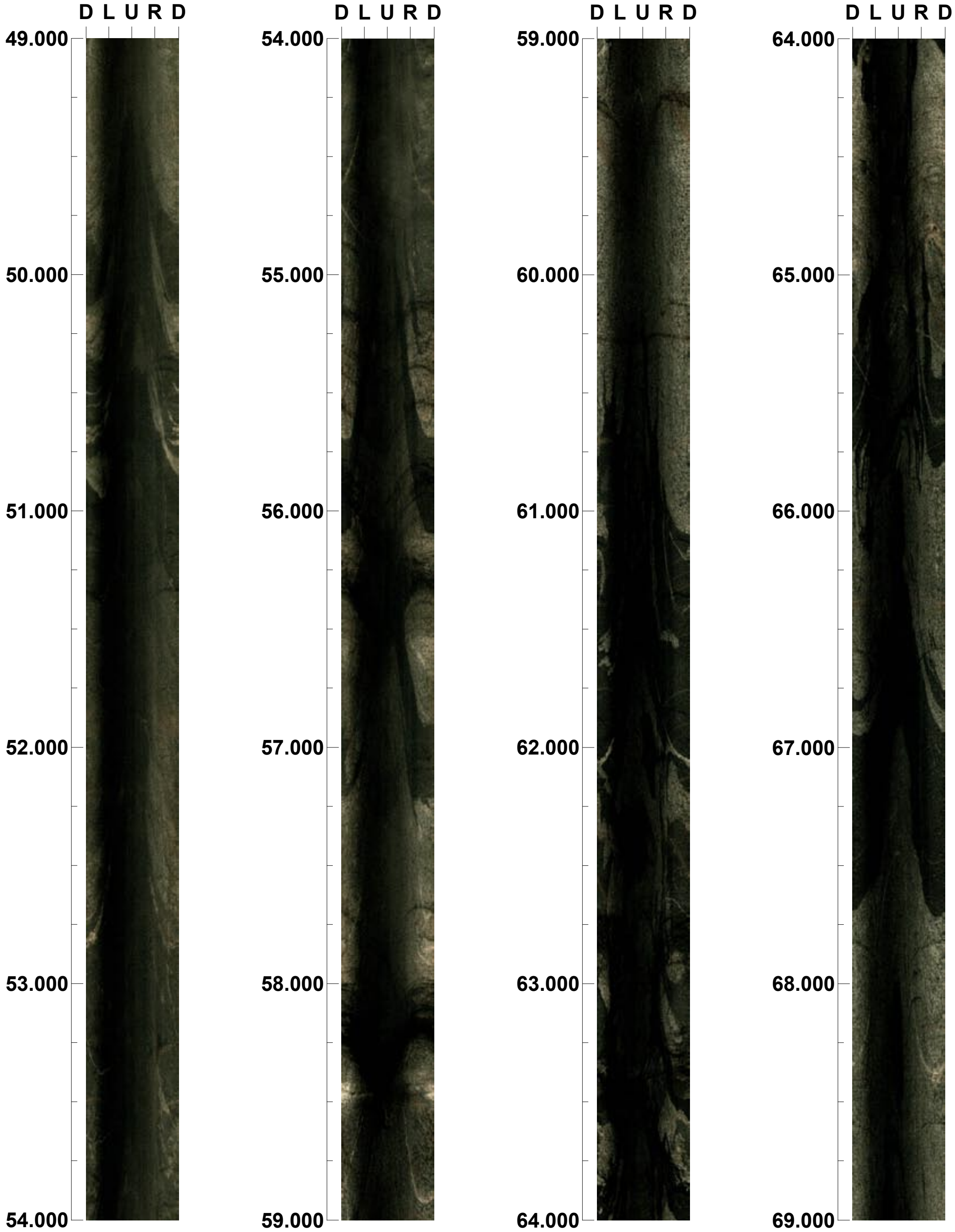
Project name: Forsmark
Bore hole No.: KFM07A **Azimuth: 260** **Inclination: 60**

Depth range: 29.000 - 49.000 m

(2 / 5) **Scale: 1/25** **Aspect ratio: 50 %**

Project name: Forsmark
Bore hole No.: KFM07A **Azimuth: 260** **Inclination: 60**

Depth range: 49.000 - 69.000 m



(3 / 5) **Scale: 1/25** **Aspect ratio: 50 %**

Project name: Forsmark
Bore hole No.: KFM07A **Azimuth: 260** **Inclination: 60**

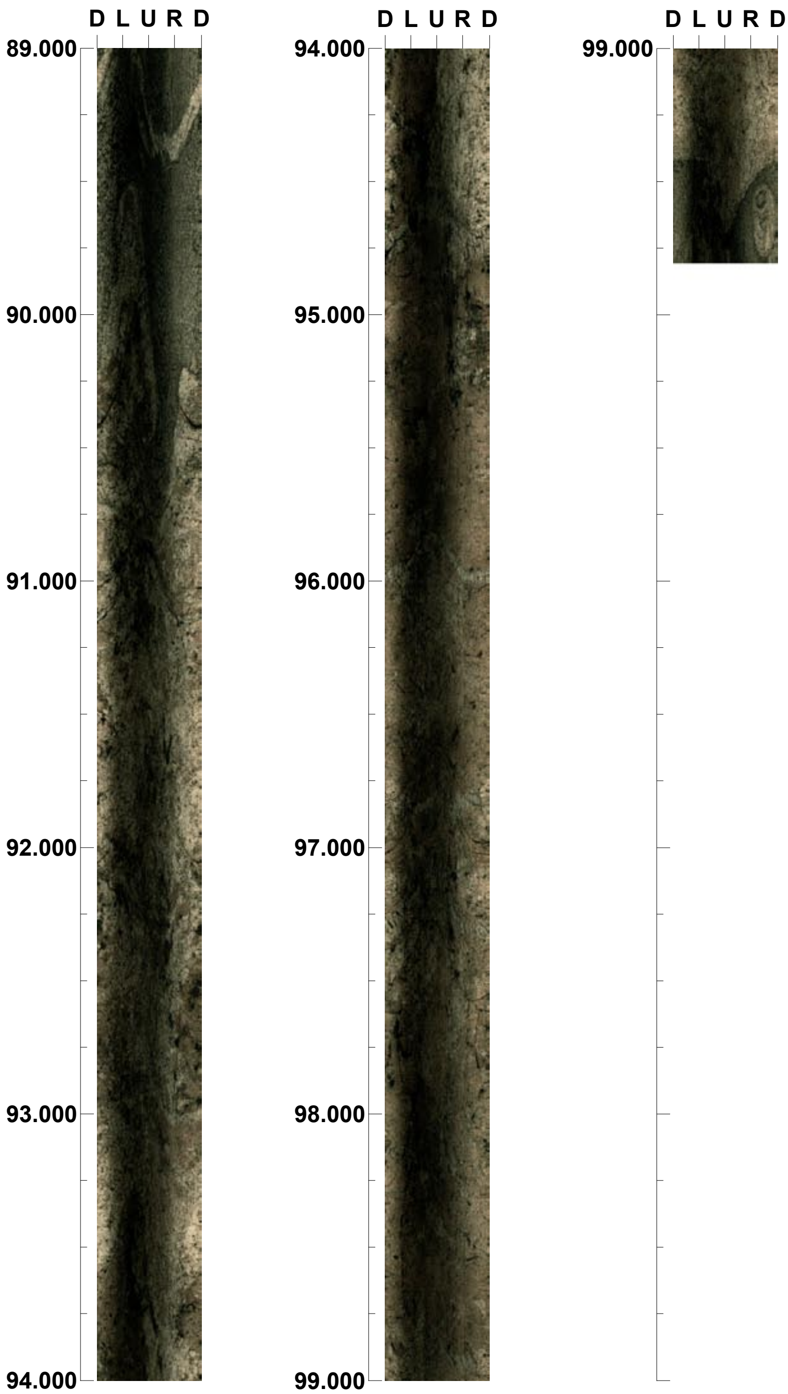
Depth range: 69.000 - 89.000 m

(4 / 5) **Scale: 1/25** **Aspect ratio: 50 %**

Project name: Forsmark

Bore hole No.: KFM07A **Azimuth: 260** **Inclination: 60**

Depth range: 89.000 - 99.806 m



(5 / 5) **Scale: 1/25** **Aspect ratio: 50 %**

Appendix 4

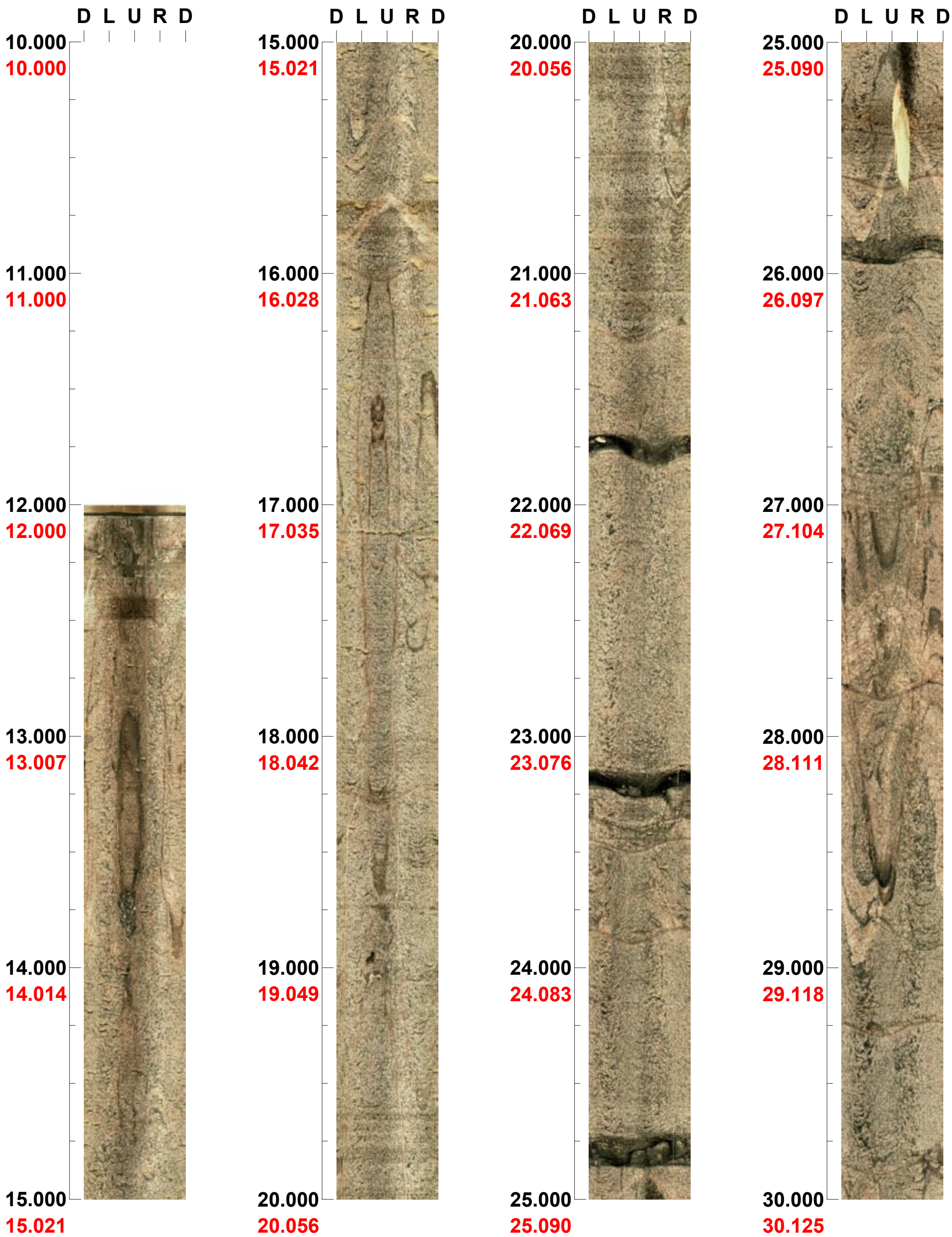
BIPS logging in HFM20, 12 to 297 m

Project name: Forsmark

Image file	: c:\work\r5317f~1\hfm20\bips\run2\hfm20.bip
BDT file	: c:\work\r5317f~1\hfm20\bips\run2\hfm20.bdt
Locality	: FORSMARK
Bore hole number	: HFM20
Date	: 04/01/18
Time	: 16:09:00
Depth range	: 12.000 - 300.030 m
Azimuth	: 350
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	: 15
Color	: +0 +0 +0

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

Depth range: 10.000 - 30.000 m



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

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

Depth range: 30.000 - 50.000 m

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

Project name: Forsmark

Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

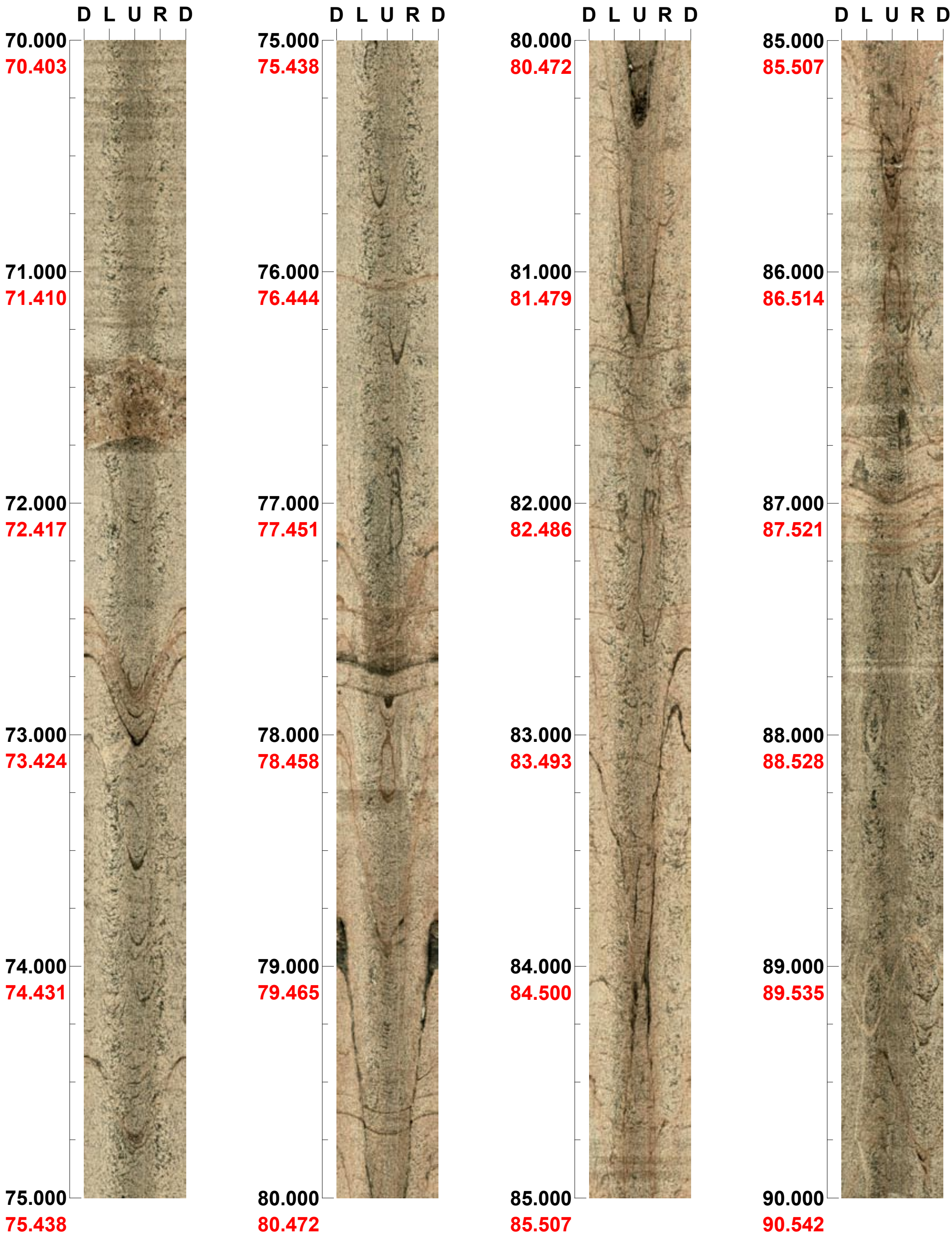
Depth range: 50.000 - 70.000 m

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

Project name: Forsmark

Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

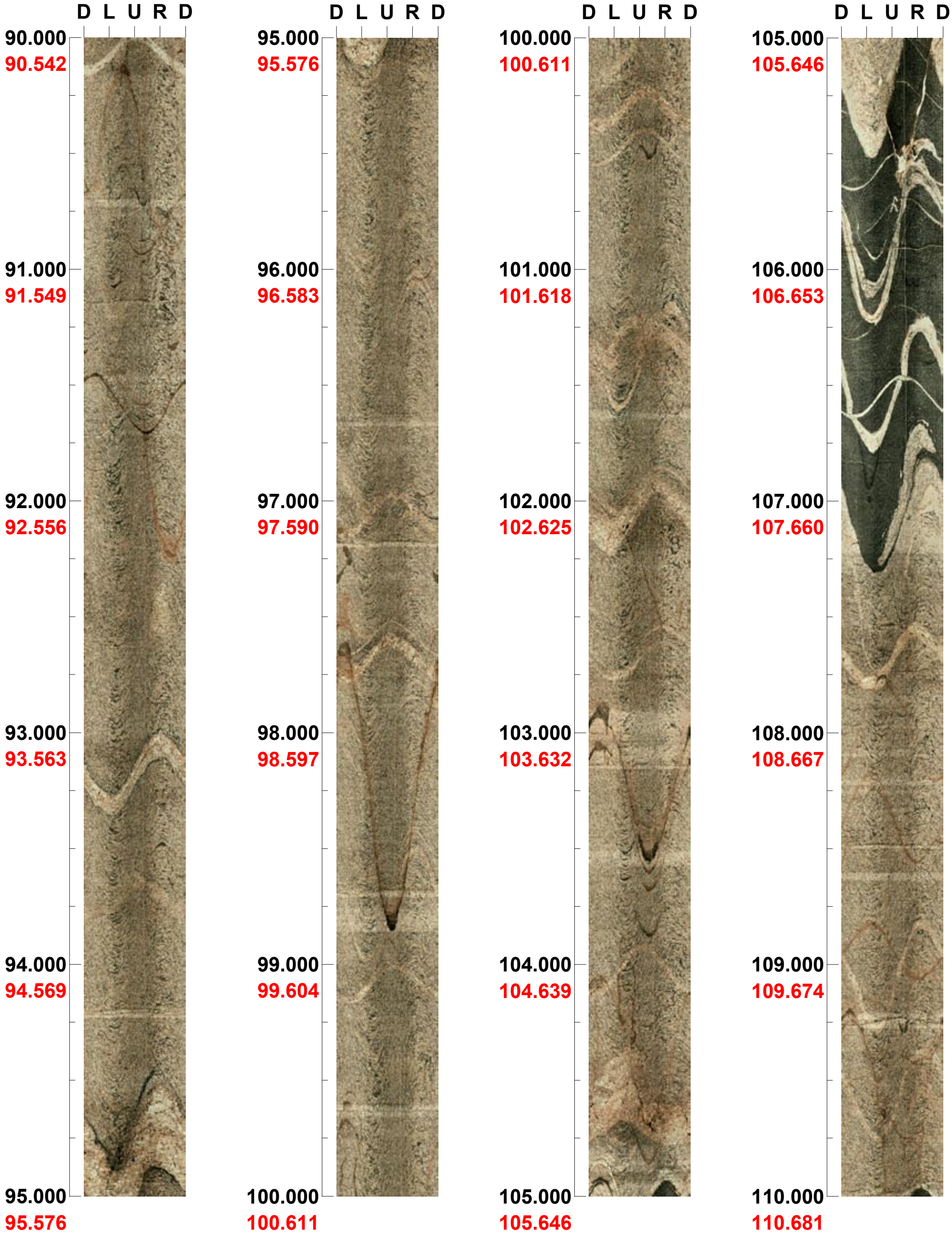
Depth range: 70.000 - 90.000 m



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

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

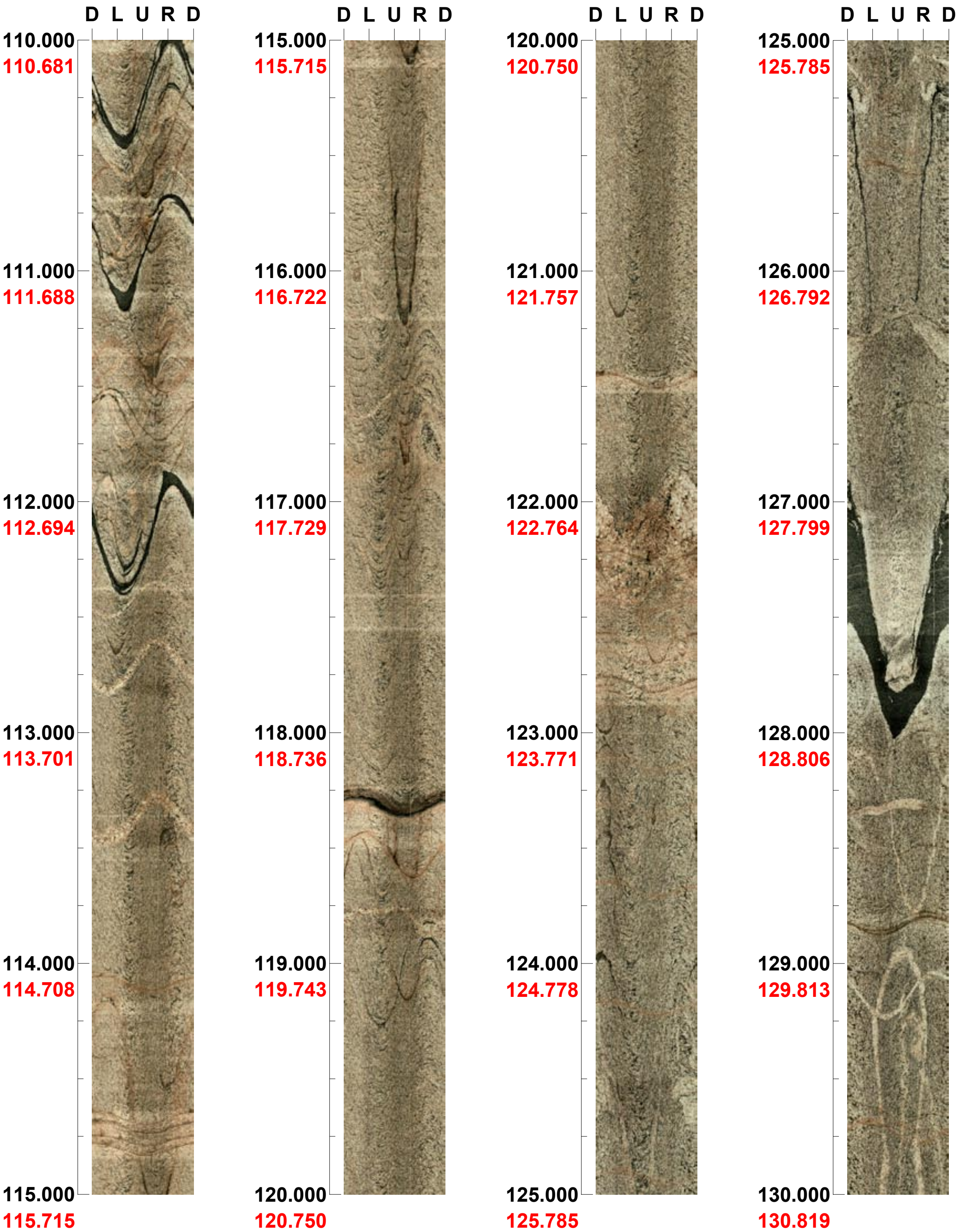
Depth range: 90.000 - 110.000 m



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

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

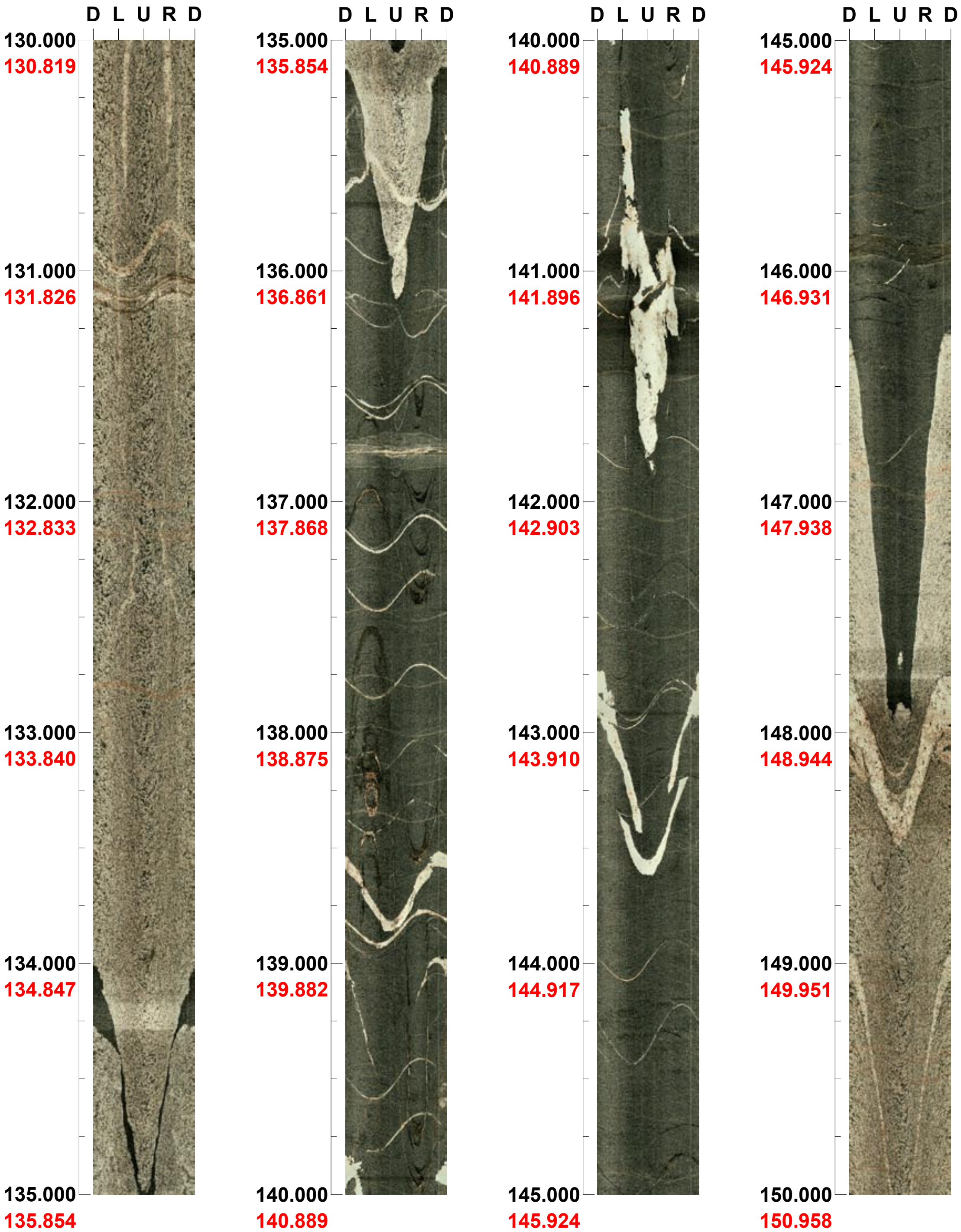
Depth range: 110.000 - 130.000 m



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

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

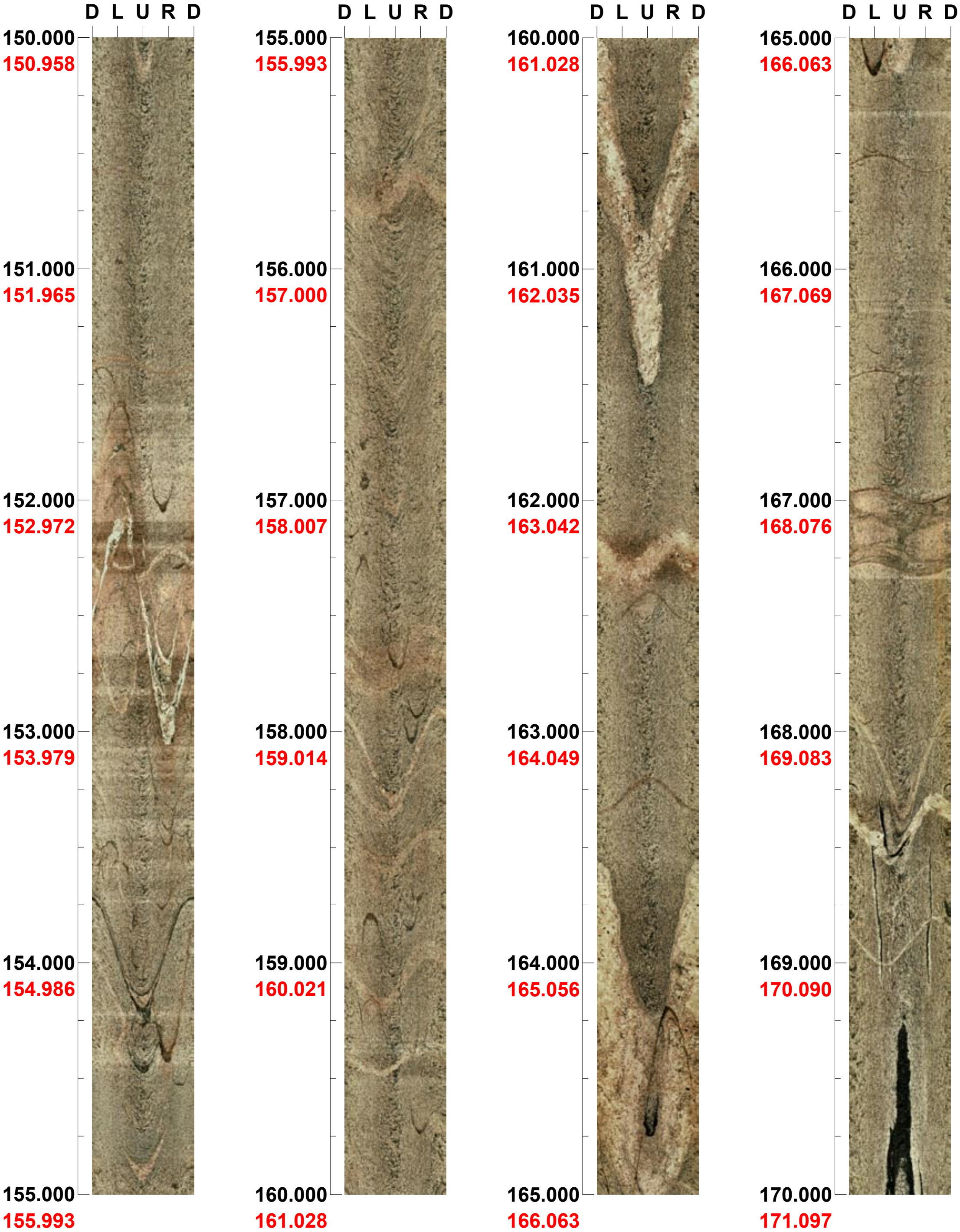
Depth range: 130.000 - 150.000 m



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

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

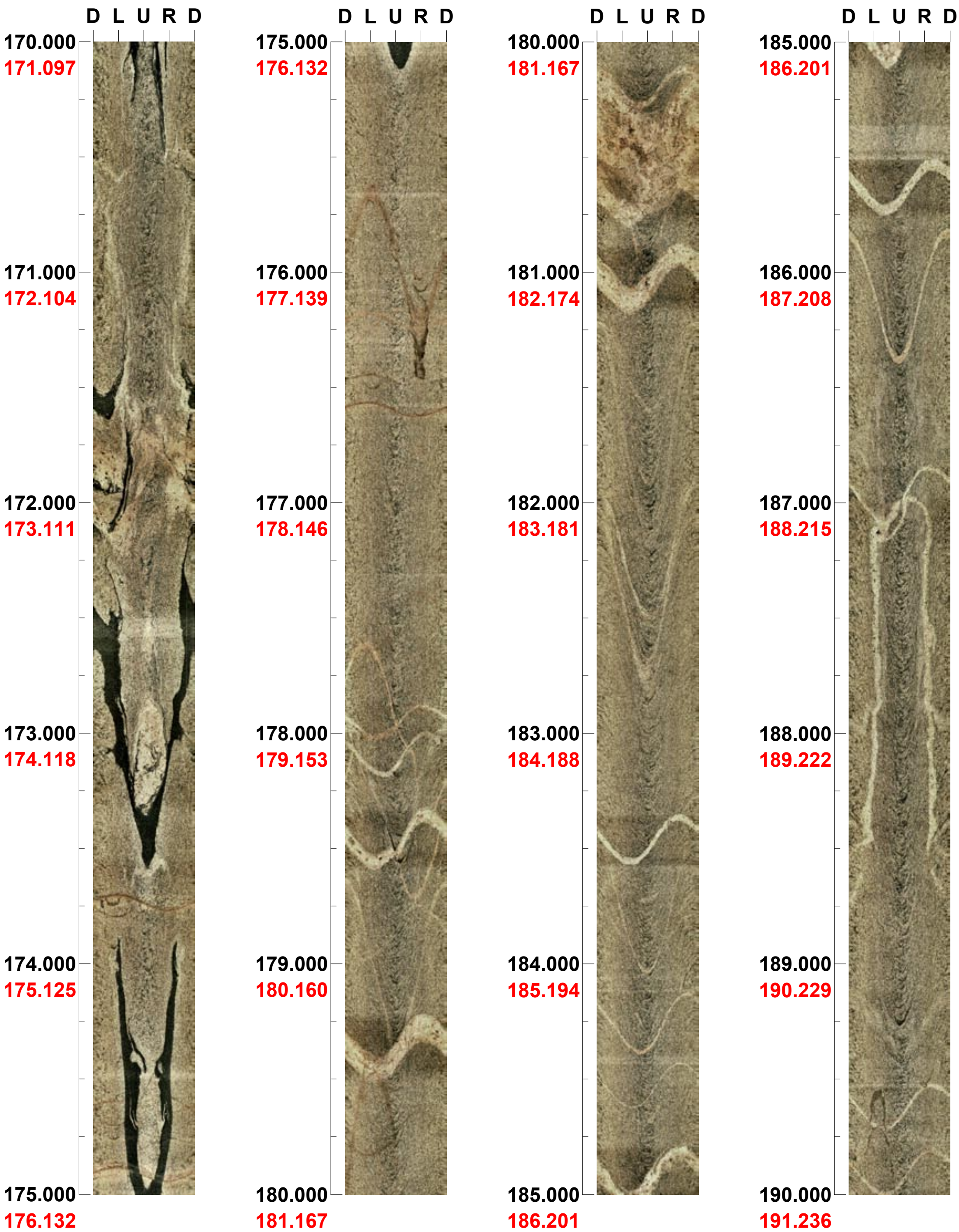
Depth range: 150.000 - 170.000 m



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

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

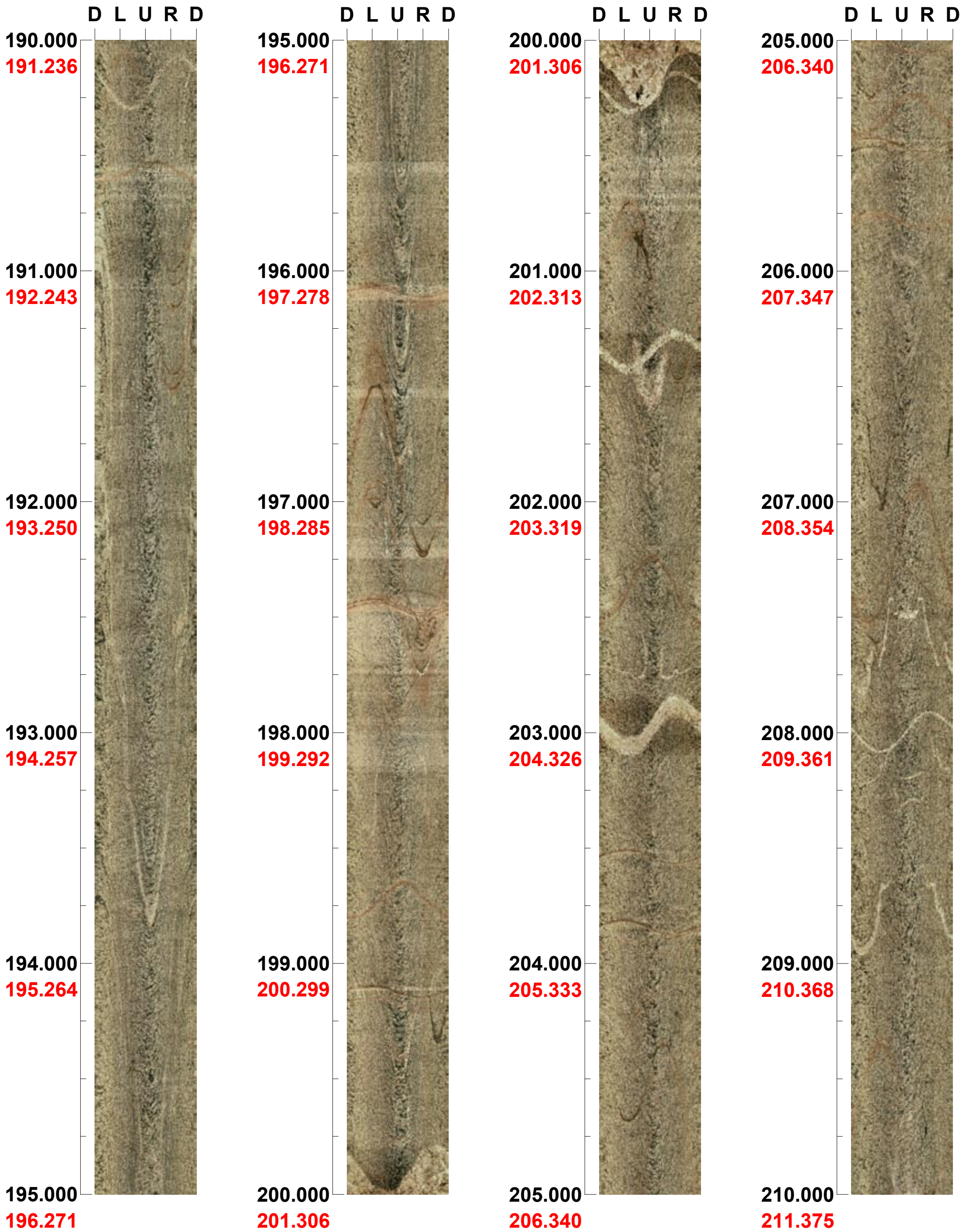
Depth range: 170.000 - 190.000 m



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

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

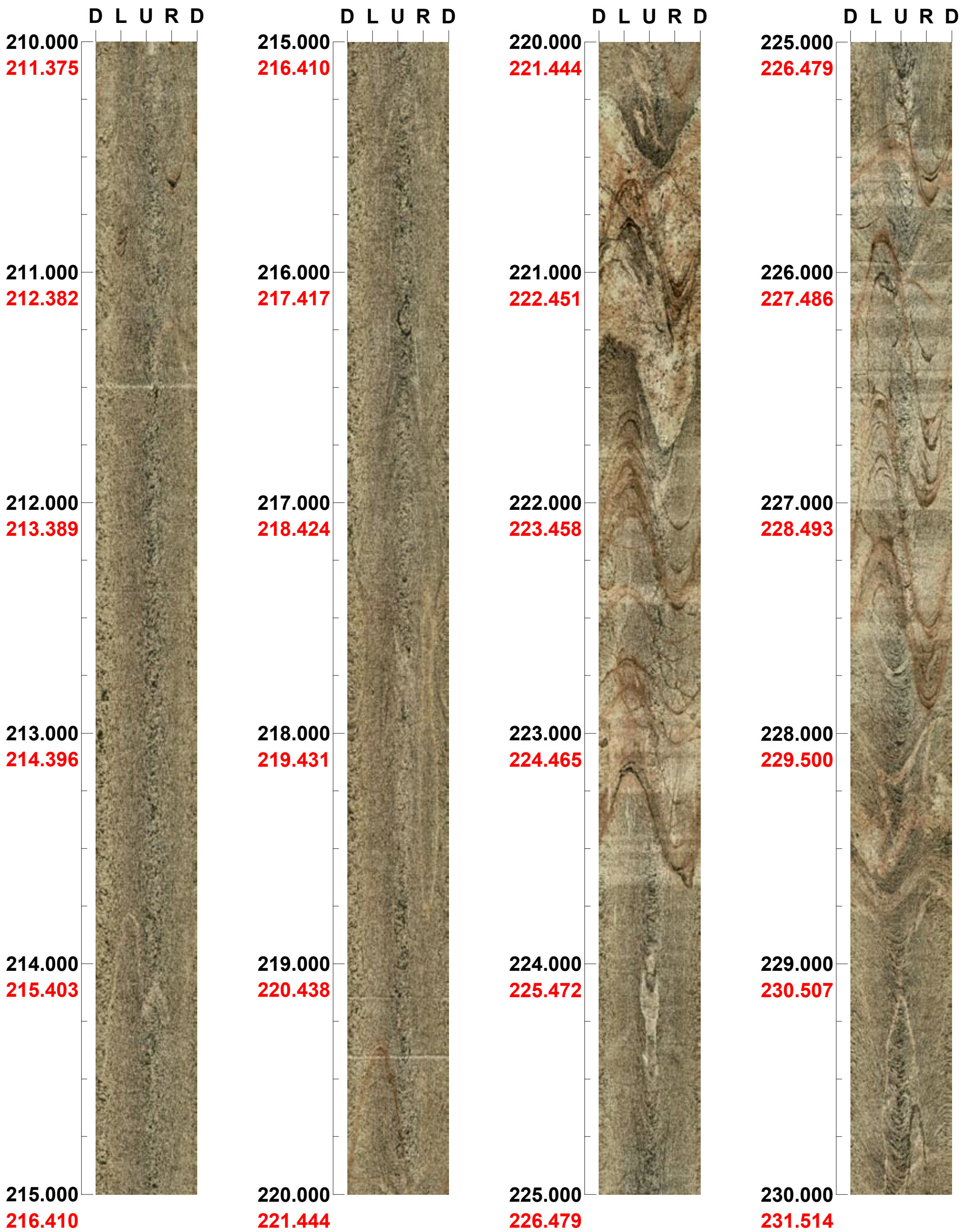
Depth range: 190.000 - 210.000 m



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

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

Depth range: 210.000 - 230.000 m

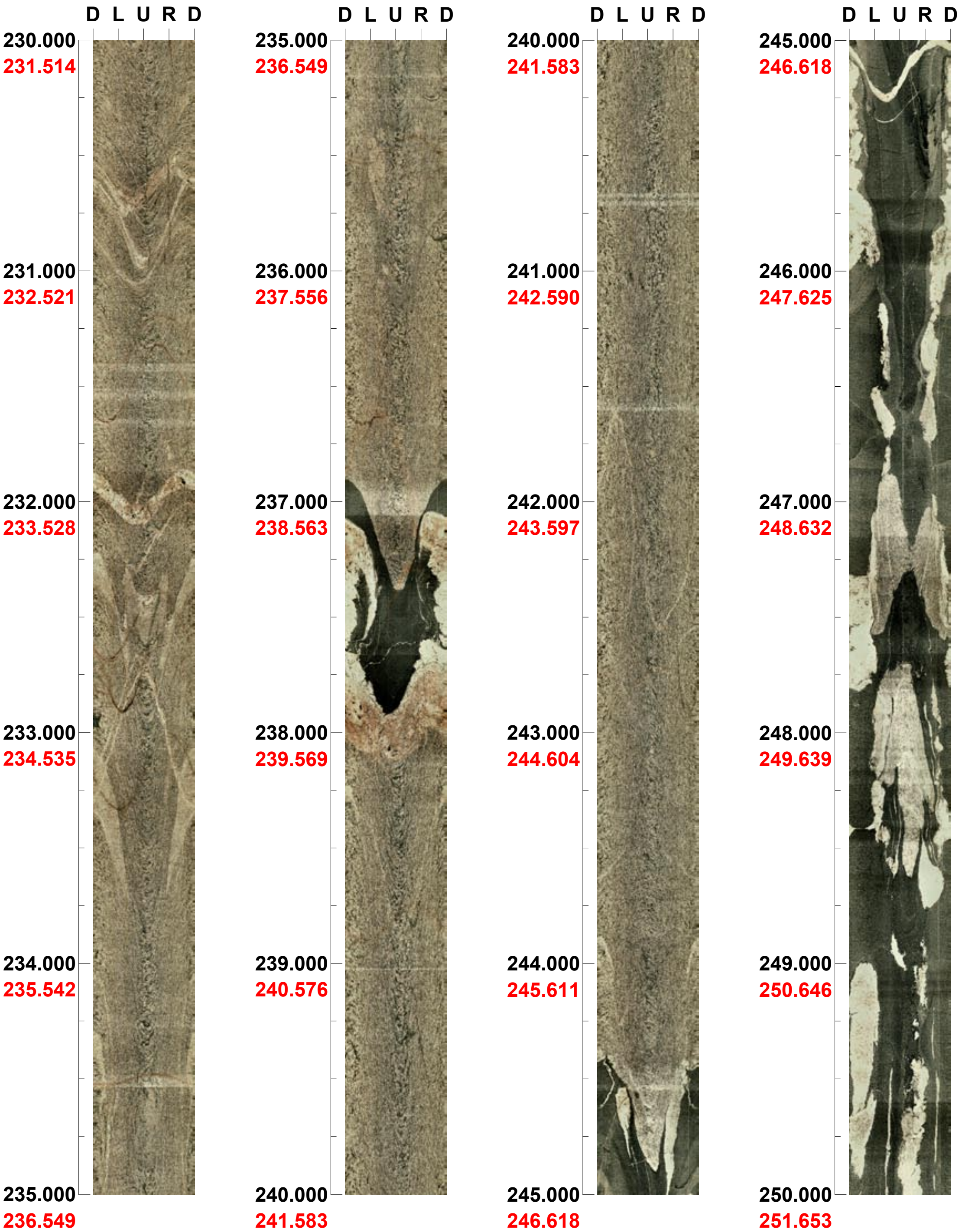


(11 / 15) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

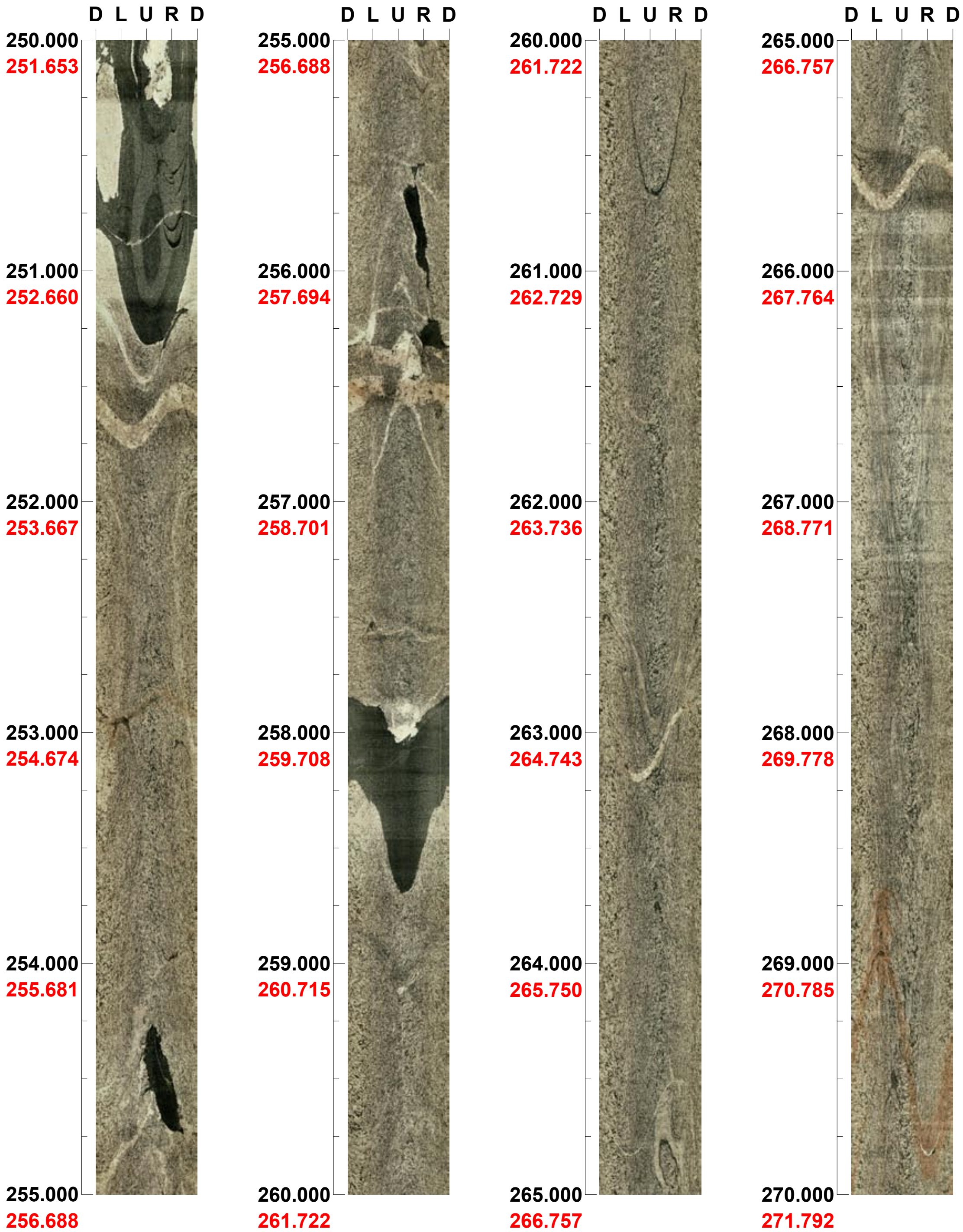
Depth range: 230.000 - 250.000 m



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

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

Depth range: 250.000 - 270.000 m



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

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

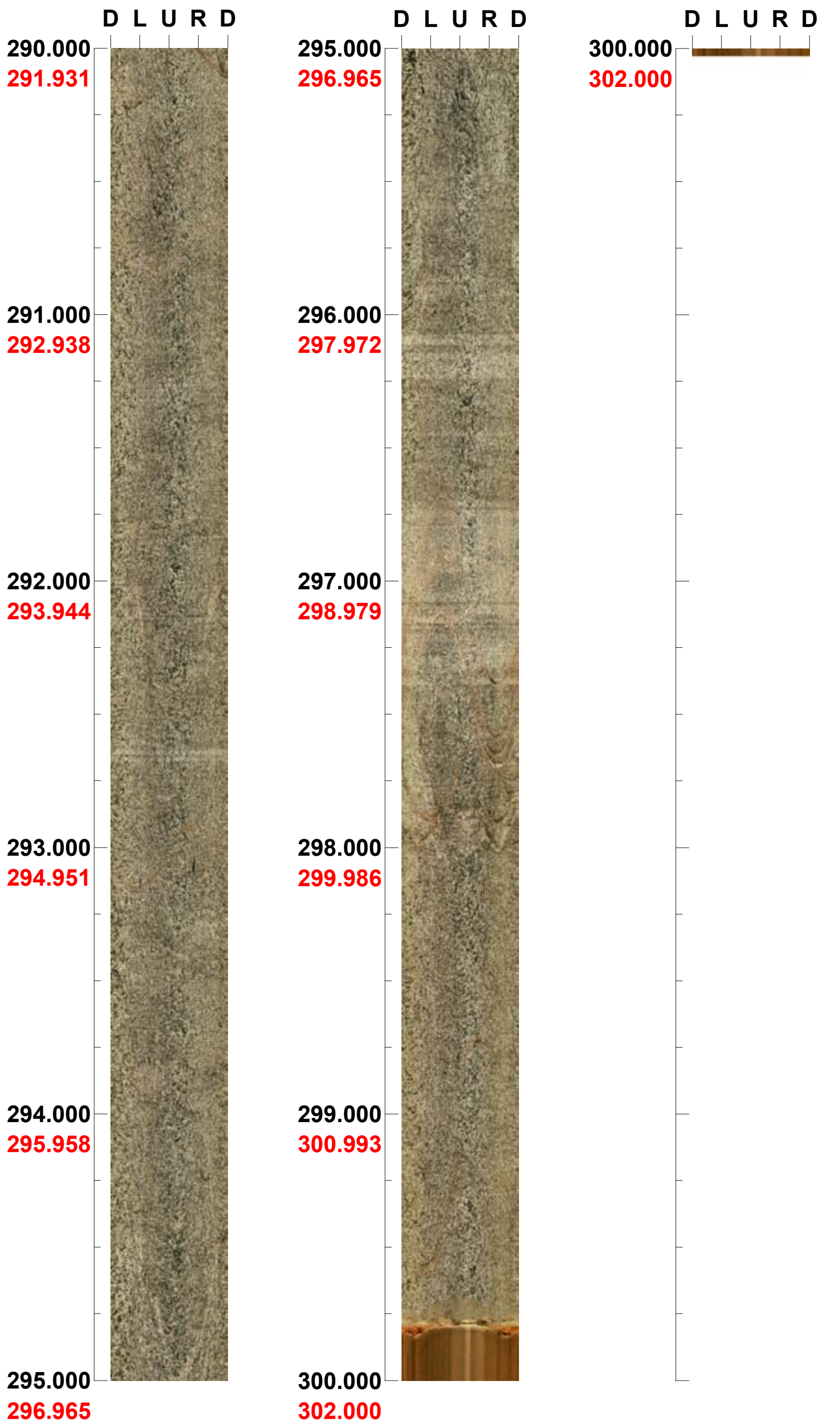
Depth range: 270.000 - 290.000 m

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

Project name: Forsmark

Bore hole No.: HFM20 **Azimuth: 350** **Inclination: -85**

Depth range: 290.000 - 300.030 m



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

Appendix 5

BIPS logging in HFM21, 12 to 202 m

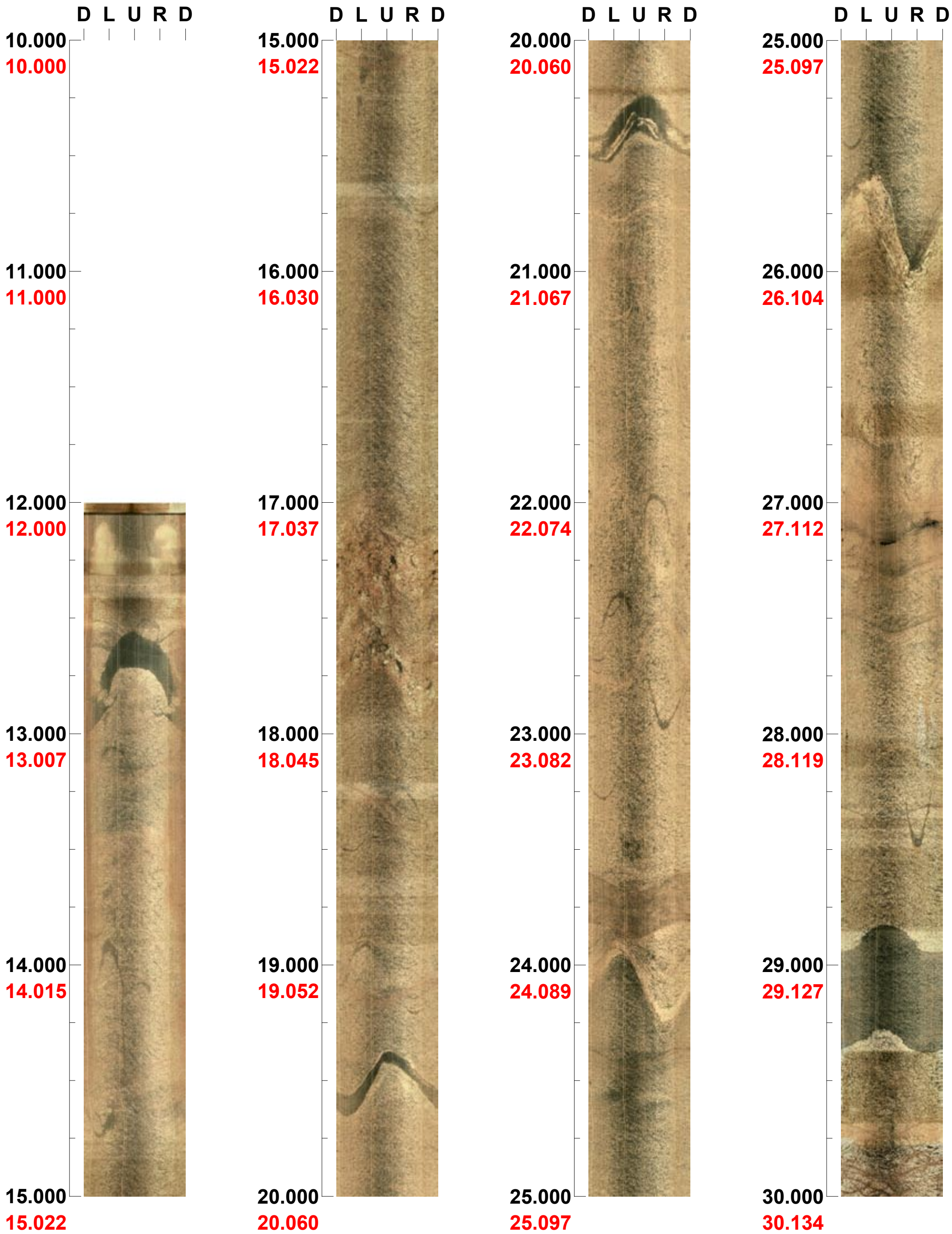
Project name: Forsmark

Image file	: c:\work\r5317f~1\hfm21\bips\run2sk~1\hfm21.bip
BDT file	: c:\work\r5317f~1\hfm21\bips\run2sk~1\hfm21.bdt
Locality	: FORSMARK
Bore hole number	: HFM21
Date	: 05/01/18
Time	: 11:10:00
Depth range	: 12.000 - 200.926 m
Azimuth	: 80
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	: 10
Color	: +0 +0 +0

Project name: Forsmark

Bore hole No.: HFM21 **Azimuth: 80** **Inclination: -60**

Depth range: 10.000 - 30.000 m

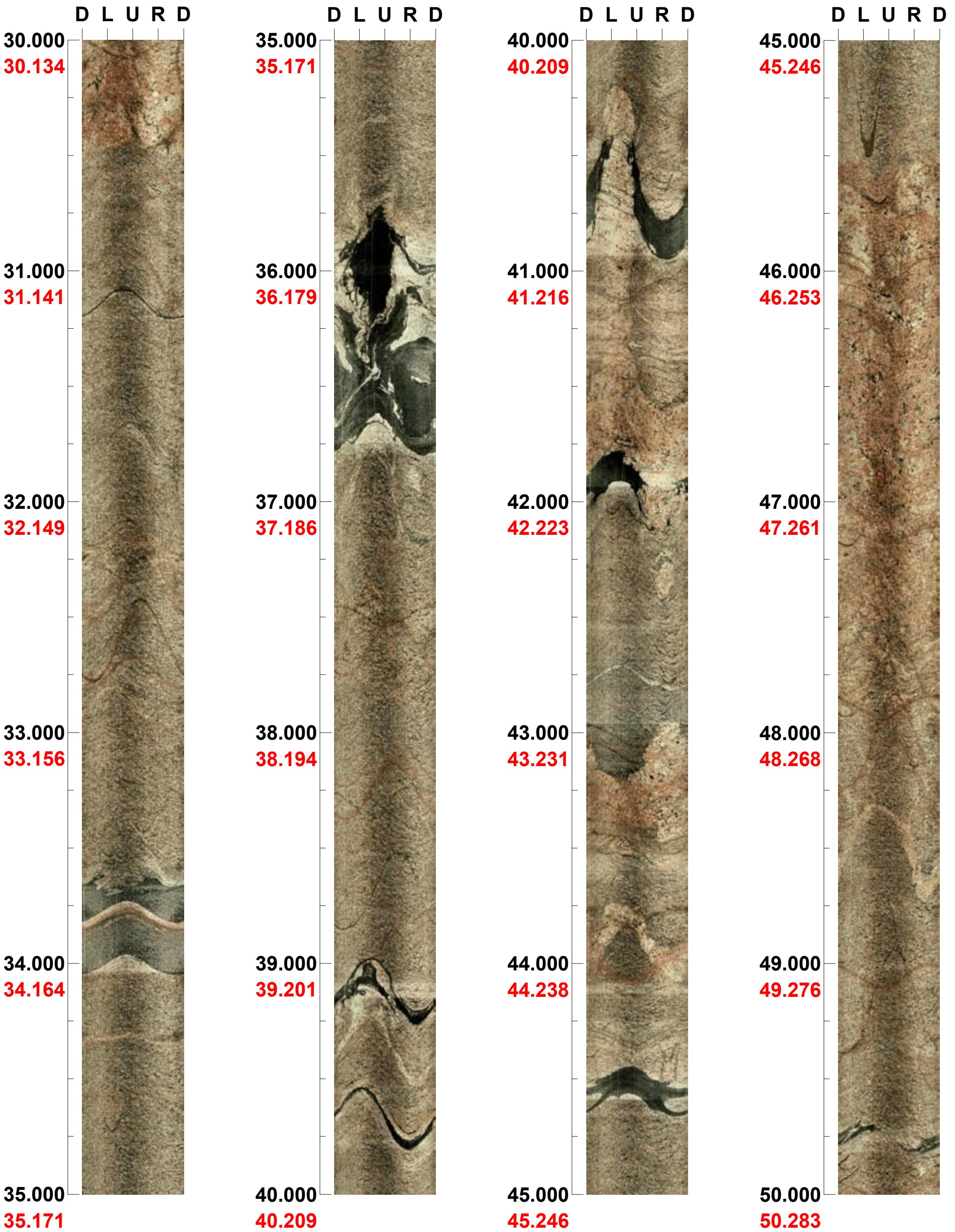


(1 / 10) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Forsmark

Bore hole No.: HFM21 **Azimuth: 80** **Inclination: -60**

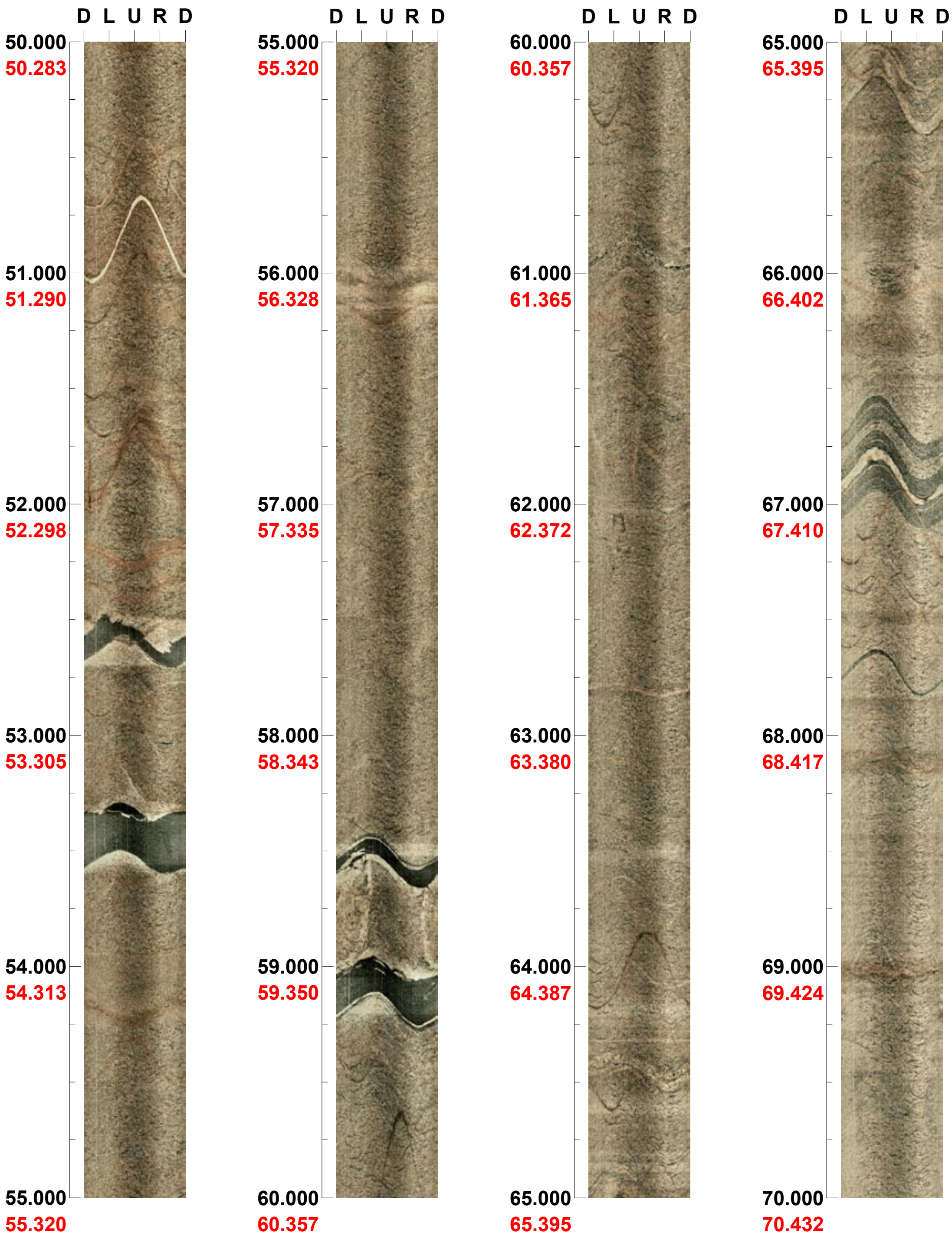
Depth range: 30.000 - 50.000 m



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

Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 80** **Inclination: -60**

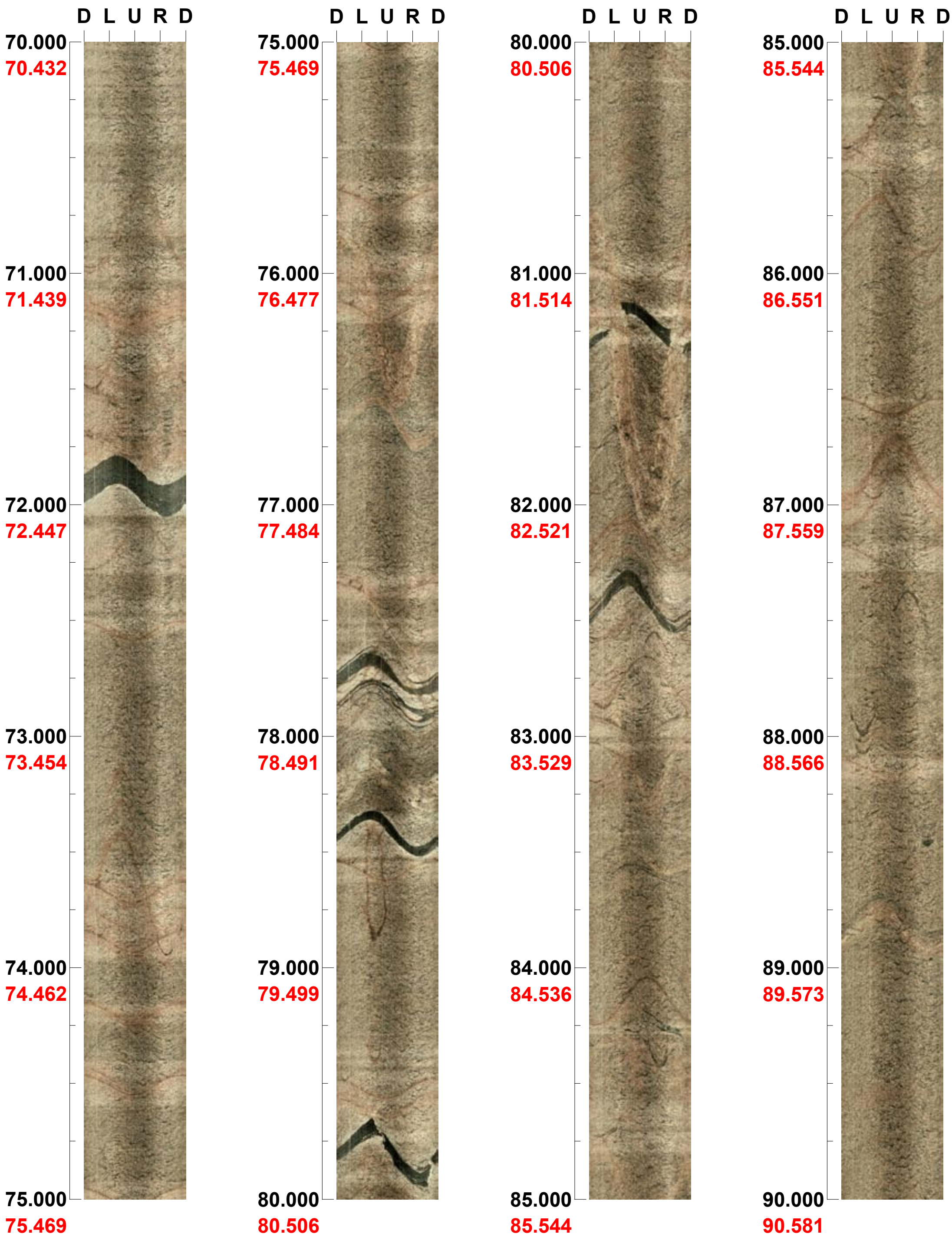
Depth range: 50.000 - 70.000 m



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

Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 80** **Inclination: -60**

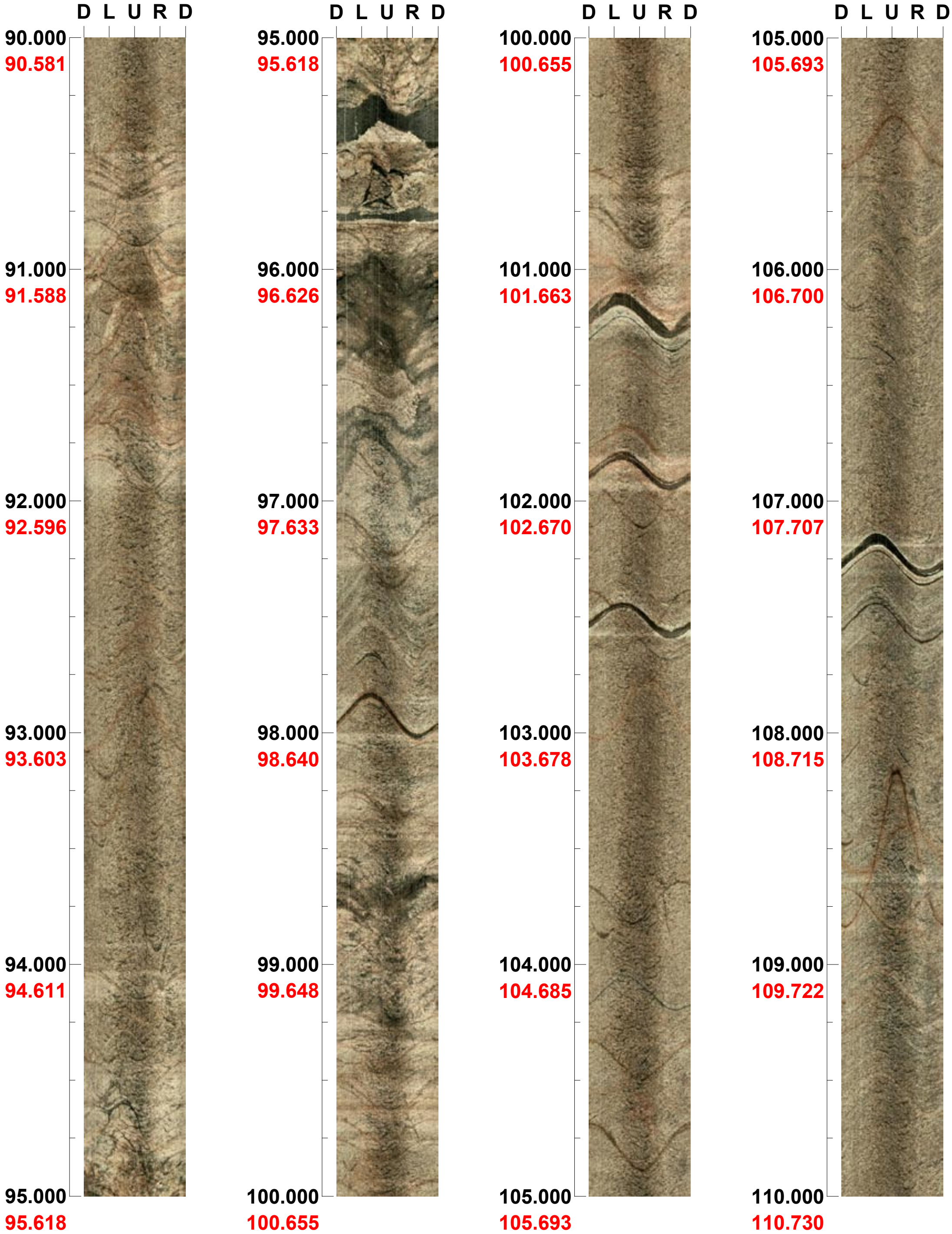
Depth range: 70.000 - 90.000 m



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

Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 80** **Inclination: -60**

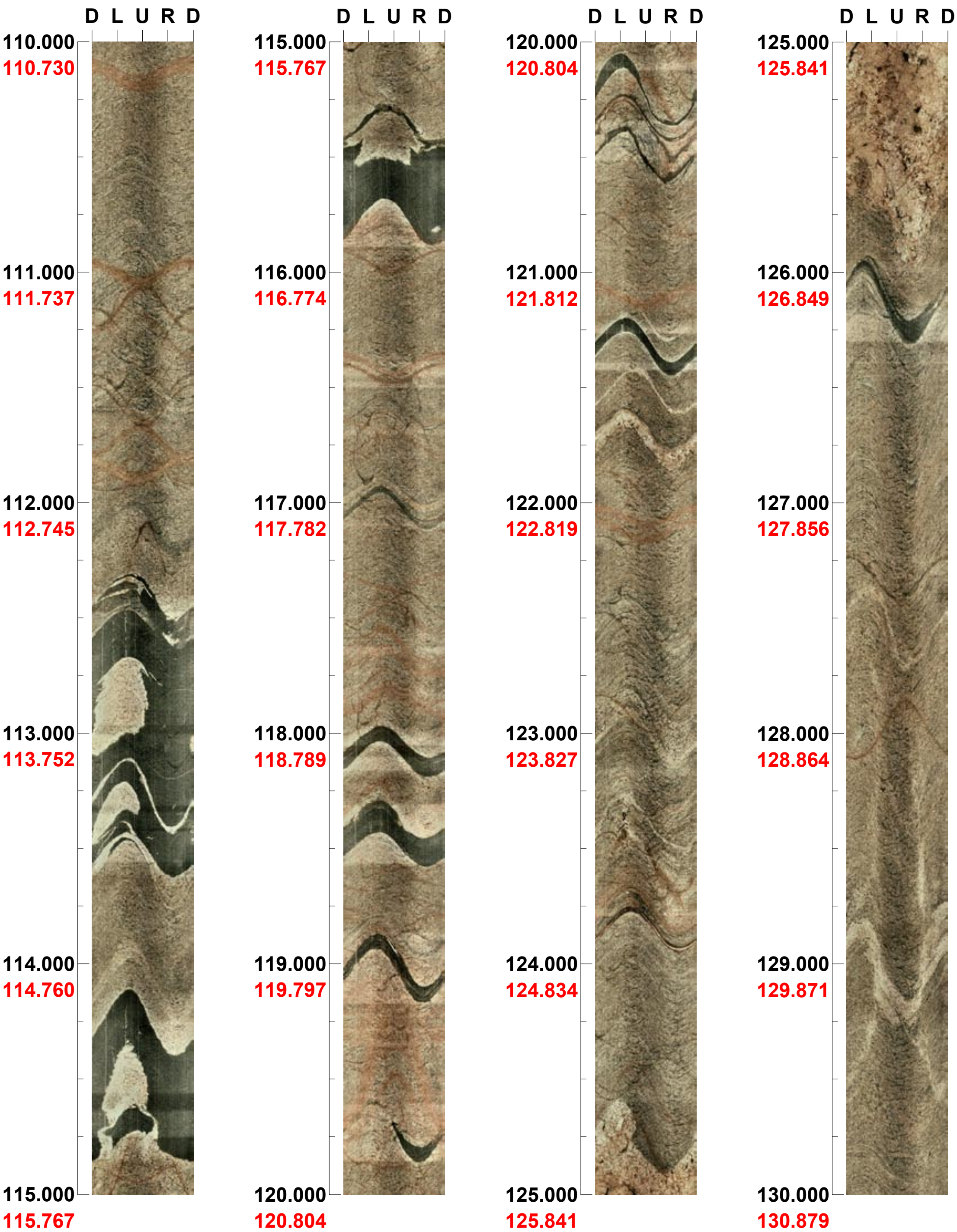
Depth range: 90.000 - 110.000 m



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

Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 80** **Inclination: -60**

Depth range: 110.000 - 130.000 m



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

Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 80** **Inclination: -60**

Depth range: 130.000 - 150.000 m

D L U R D

130.000 / 130.879
131.000 / 131.886
132.000 / 132.894
133.000 / 133.901
134.000 / 134.909
135.000 / 135.916

D L U R D

135.000 / 135.916
136.000 / 136.923
137.000 / 137.931
138.000 / 138.938
139.000 / 139.946
140.000 / 140.953

D L U R D

140.000 / 140.953
141.000 / 141.961
142.000 / 142.968
143.000 / 143.976
144.000 / 144.983
145.000 / 145.990

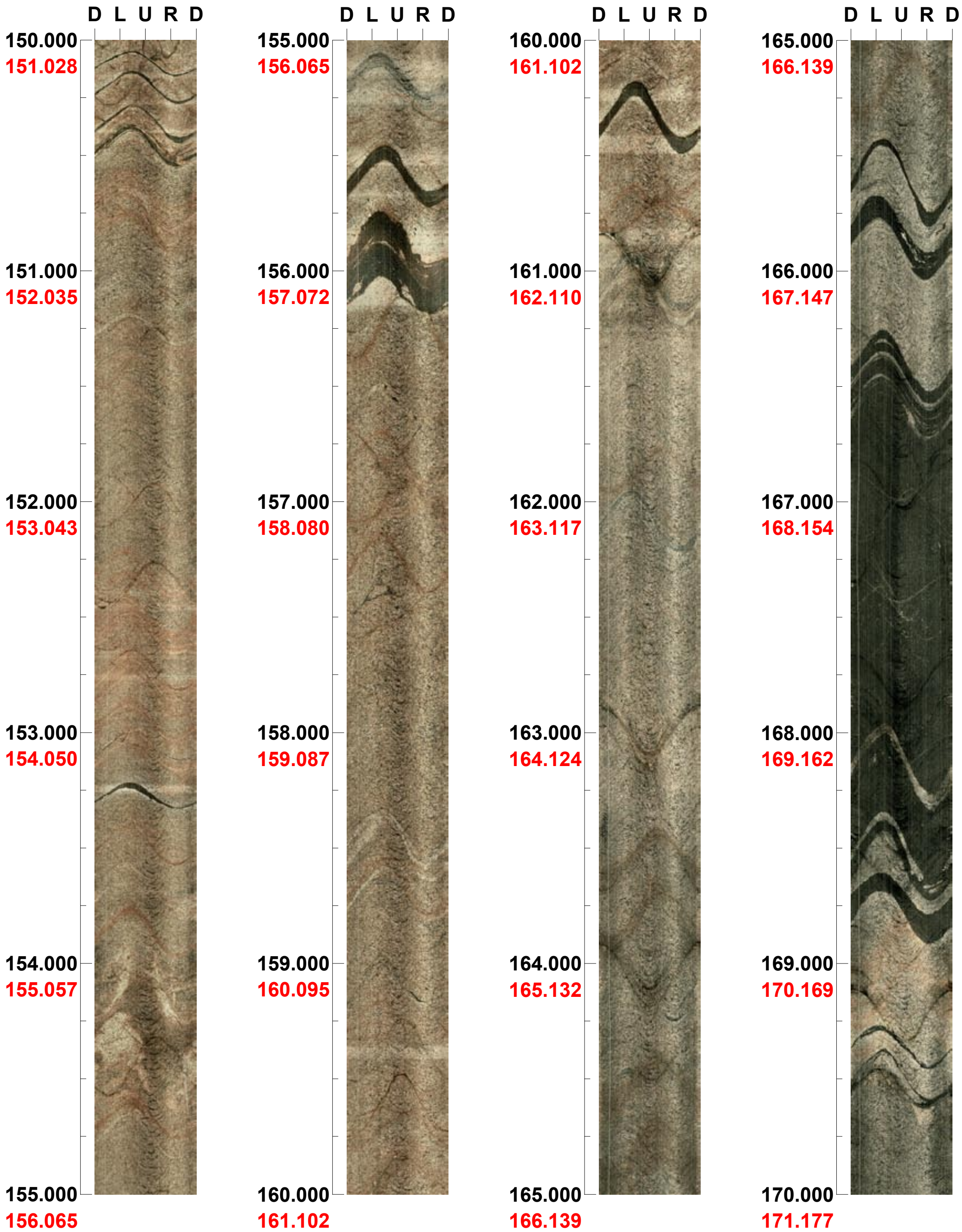
D L U R D

145.000 / 145.990
146.000 / 146.998
147.000 / 148.005
148.000 / 149.013
149.000 / 150.020
150.000 / 151.028

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

Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 80** **Inclination: -60**

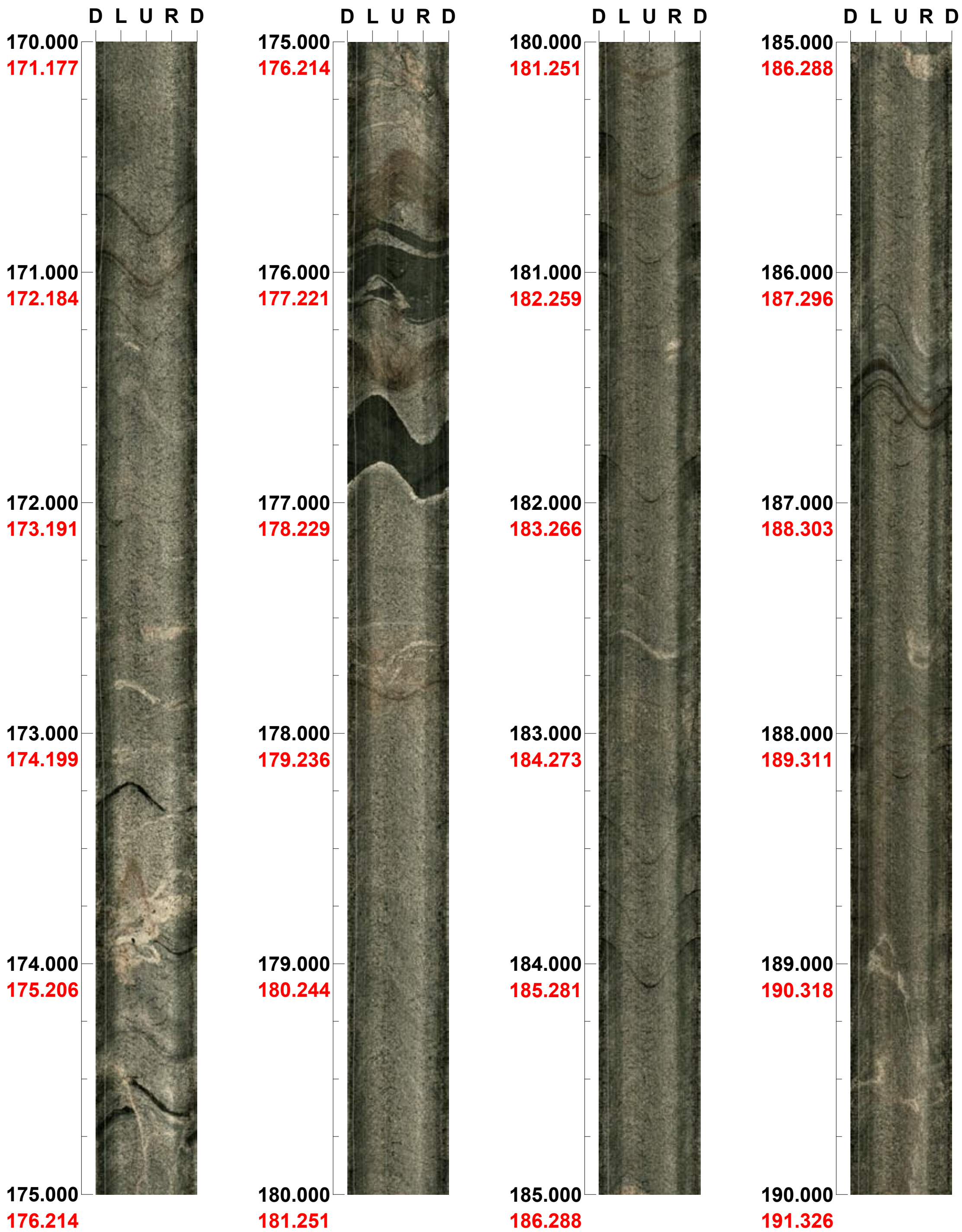
Depth range: 150.000 - 170.000 m



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

Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 80** **Inclination: -60**

Depth range: 170.000 - 190.000 m



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

Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 80** **Inclination: -60**

Depth range: 190.000 - 200.926 m

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