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Forsmark site investigation

RAMAC and BIPS logging in borehole KFM11A

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January 2007

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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 and borehole radar (RAMAC) logging in the core-drilled borehole KFM11A. All measurements were conducted by Malå Geoscience AB during November 2006.

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 surveys, the results are presented as images. Radar data is presented in radargrams and the identified reflectors are listed.

The borehole radar data quality from KFM11A was satisfying to good, but in some parts of lower quality due to high electric conductivity of the borehole fluid. This conductive environment 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 234 identified radar reflectors of which 46 were orientated (dip/strike).

The BIPS images from KFM11A is of medium quality. It is mainly mud covering the lowermost part of the borehole wall and bad water quality that lowers the image quality.

Sammanfattning

Denna rapport omfattar geofysiska loggningar inom platsundersökningsprogrammet för Forsmark. Mätningarna som presenteras här omfattar BIPS-loggning och borrhålsradarmätningar (RAMAC) i kärnborrhålet KFM11A. Alla mätningar är utförda av Malå Geoscience AB under november 2006.

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 loggningarna presenteras data i form av plottar längs med borrhålet. Radardata presenteras i radargram, och en lista över tolkade radarreflektorer ges.

Borrhålsradardata från KFM11A var tillfredställande till bra, men tidvis av sämre kvalité, troligen till stor del beroende på en elektrisk konduktiv miljö. En hög elektrisk konduktivitet minskar möjligheterna att identifiera strukturer från borrhålsradardata. Dock har 234 radarreflektorer identifierats i KFM11A, varav 46 är orienterade (strykning och stupning).

BIPS bilderna från KFM11A uppvisar mediumkvalitet. Det är främst kax från borrningen som täcker borrhålsväggens nedre del tillsammans med dålig vattenkvalitet som försämrar kvaliteten.

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 TV-logging (BIPS) and borehole radar (RAMAC) in the core-drilled borehole KFM11A. The work was carried out in accordance with activity plan AP PF 400-06-092. 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 approximately 70 m to approximately 840 m in borehole KFM11A. The borehole diameter in this depth is 77.3 mm.

All measurements were conducted by Malå Geoscience AB during November 2006. Figure 1-1 shows the borehole location.

The used investigation techniques comprised:

- Borehole radar measurements (Malå Geoscience AB's RAMAC system) with dipole and directional antennas.
- Borehole TV logging with the Borehole Image Processing System (BIPS) 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
BIPS- och RADAR-loggning i teleskopborrhålet KFM11A	AP PF 400-06-092	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	3.0

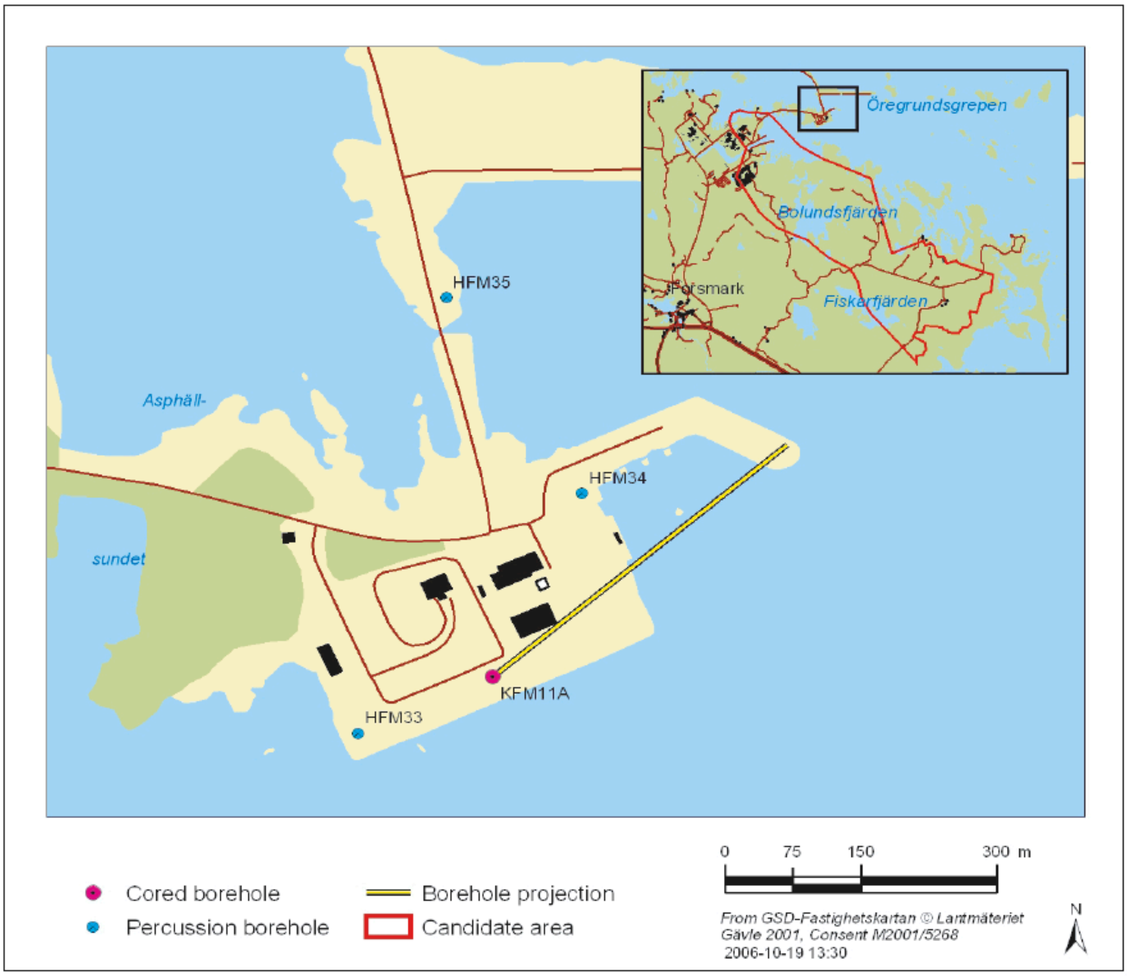


Figure 1-1. *Overview over the Forsmark investigation area and Drill Site 11, showing the location of the borehole KFM11A surveyed and presented in this report.*

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 as the measurement procedures and data gained. For the BIPS surveys, the results are presented as images. Radar data are 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. Structural features, e.g. a water-filled fractures with sufficiently different electrical properties, causes reflected pulses which are recorded by the receiver.

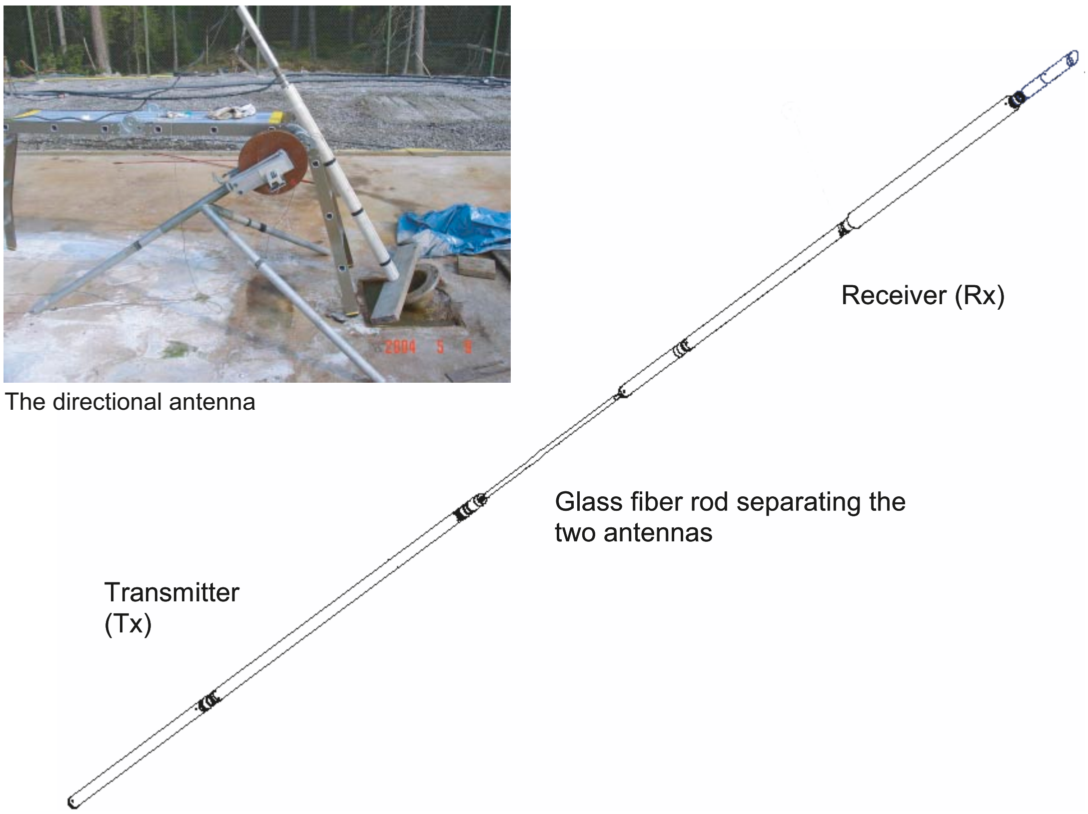


Figure 3-1. *Example of a borehole radar antenna.*

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 (in near-vertical boreholes) or with a gravity sensor (in inclined boreholes).

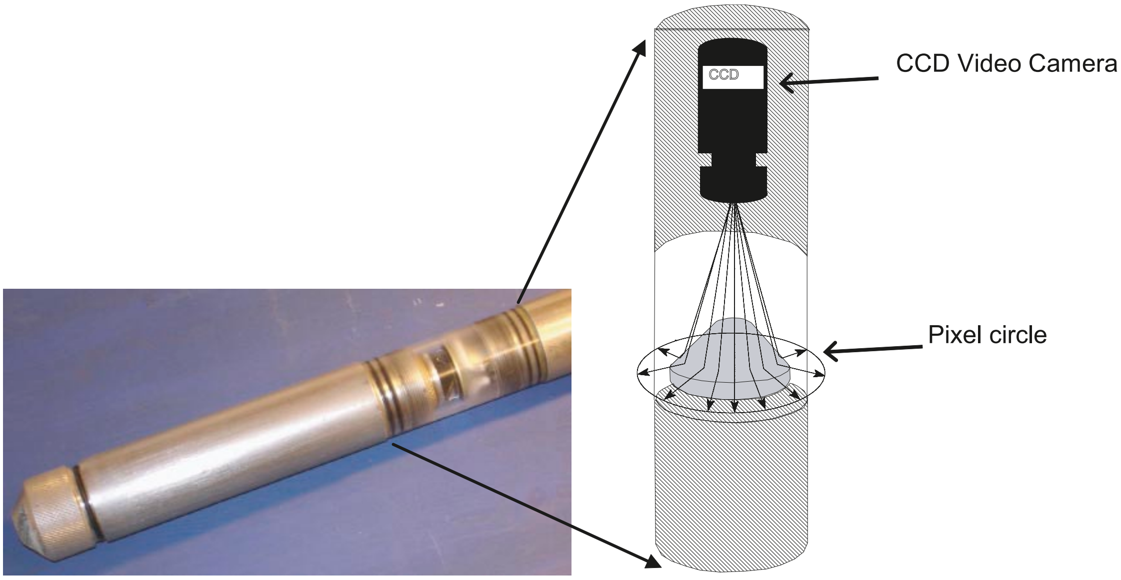


Figure 3-2. *The BIP-system. To the right a sketch showing the principles of the conical mirror.*

4 Execution

4.1 General

4.1.1 RAMAC Radar

The measurements in KFM11A were carried out with dipole radar antennas with frequencies of 250, 100 and 20 MHz. Measurements were also carried out using the directional antenna, 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 computer 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, both for dipole and directional) 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). Before the logging operation, the antennas and cable were cleaned according to the internal document SKB MD 600.004.

The functionality of the directional antenna was tested before measurements in KFM11A. This was performed 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 is measured by compass and the result difference achieved from the directional antenna was about 23 degrees. This can be considered to be satisfying, considering the very disturbed environment with metallic objects etc at the test site, see Figure 4-2.

For more information on system settings used in the investigation of KFM11A, see Table 4-1.

Table 4-1. Radar logging information from KFM11A.

Site:	**Forsmark**	**Logging company:**	**Malå Geoscience AB**		
BH:	**KFM11A**	**Equipment:**	**SKB RAMAC**		
Type:	**Directional/Dipole**	**Manufacturer:**	**MALÅ Geoscience AB**		
Operator:	**CG**	**Antenna**			
		Directional	**250 MHz**	**100 MHz**	**20 MHz**
Logging date:		2006-11-25 to 2006-11-26	2006-11-25	2006-11-25	2006-11-25
Reference:		T.O.C.	T.O.C.	T.O.C.	T.O.C.
Sampling frequency (MHz):		615	2,424	891	239
Number of samples:		512	619	518	518
Number of stacks:		32	Auto	Auto	Auto
Signal position:		410.5	–0.36	–0.36	–1.42
Logging from (m):		73.4	71.5	72.6	76.25
Logging to (m):		833.4	844.4	844.4	840.05
Trace interval (m):		0.5	0.1	0.2	0.25
Antenna separation (m):		5.73	2.4	3.9	10.05

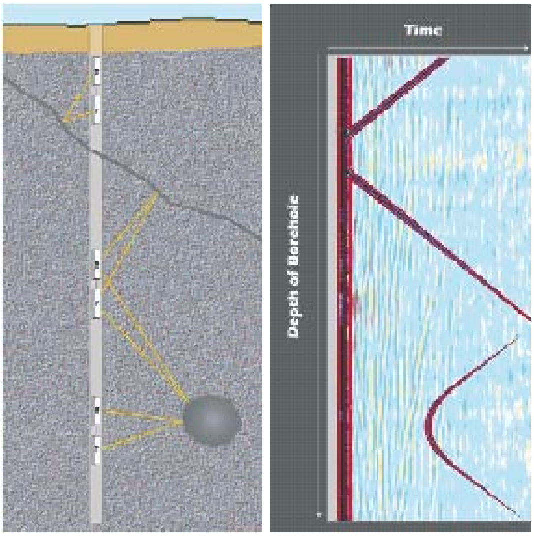


Figure 4-1. *The principle of radar borehole reflection survey (left) and an example of result (right).*

Figure 4-2. *Photo of the surroundings during the functionality test of the directional antenna. The receiver antenna is seen in the middle of the picture, very close to a steel cable.*

4.1.2 BIPS

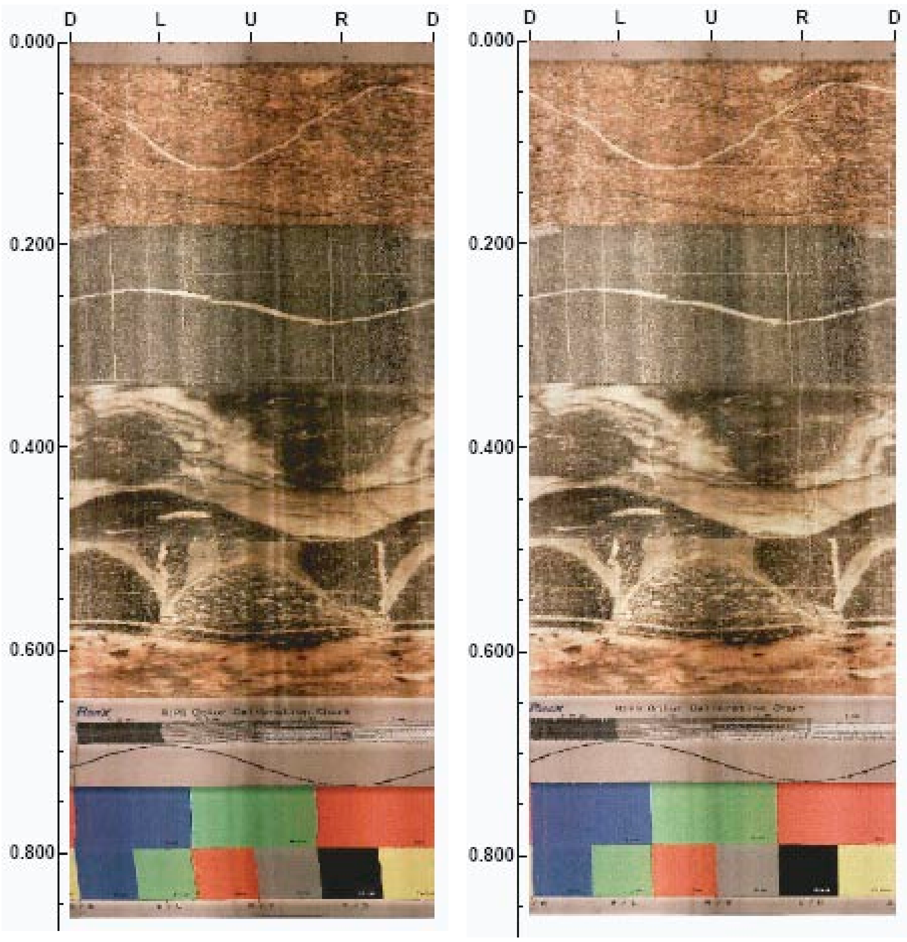
All measurements were performed in accordance with the instructions and guidelines from SKB (internal document MD 222.006). All cleaning of the probe and cable was performed according to the internal document SKB MD 600.004 before the logging operation.

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.

A gravity sensor was used to measure the orientation of the images in borehole KFM11A.

In order to control the image quality of the system, calibration measurements were performed in a test pipe before logging and after logging, see Figure 4-3. 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 in the presentation in Appendix 2.



Before logging in KFM11A **After logging in KFM11A**

Figure 4-3. *Results from logging in the test pipe before and after the logging campaign in November, 24th to 26th, 2006. The length scales are not essential in the test measurements.*

4.1.3 Length measurements

During logging the length recording for the RAMAC systems is taken care of by a measuring wheel mounted on the cable winch. The logging is measured from TOC (Top of Casing). The length is adjusted to the bottom of casing when visible in the BIPS image.

During the BIPS logging in core drilled boreholes, where the reference marks in the borehole wall is visible on the image, the position where the length mark is visible is marked with scotch tape on the logging cable. During BIPS logging the measured length was adjusted to true length according to length mark visible in the BIPS image. The adjusted true length is marked with red figures in the image plot together with the non-adjusted measured length. The non-adjusted length is marked with black figures as seen in Appendix 2. The tape marks on the logging cable are then used for controlling the RAMAC measurement.

The experience we have from earlier measurements with dipole antennas in the core drilled boreholes in Forsmark and Oskarshamn is that the length divergence is less than 100 cm in the deepest parts of a 1,000 metres long borehole. The length divergence is taken into account in the resulting tables in Chapter 5.

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 etc) 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 advantages and 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 4-4, and the calculation shows a velocity of 128 m/µs (metres per microsecond) /1/. The velocity measurement was performed with the 100 MHz antenna.

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 for the data presented in Appendix 1 are given in Table 4-2. 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.

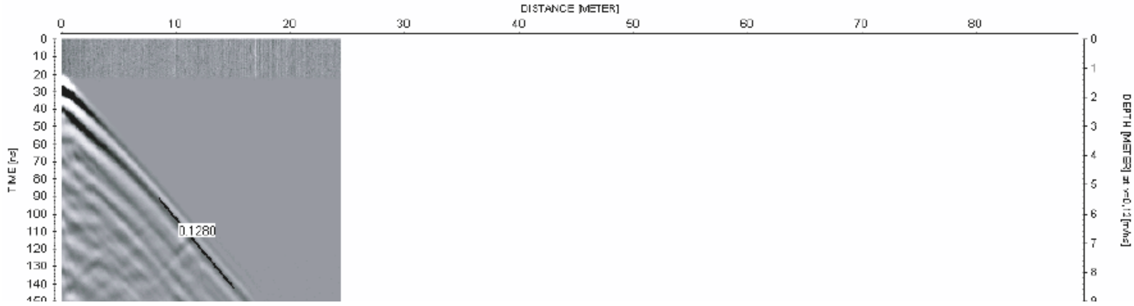


Figure 4-4. Results from velocity measurements in HFM03.

Table 4-2. Processing steps for borehole radar data from KFM11A.

Site:	**Forsmark**	**Logging company:**	**MALÅ GeoScience AB**		
BH:	**KFM11A**	**Equipment:**	**SKB RAMAC**		
Type:	**Directional/Dipole**	**Manufacturer:**	**MALÅ GeoScience AB**		
Interpret:	**JG**	**Antenna**			
		Directional	**250 MHz**	**100 MHz**	**20 MHz**
Processing steps		Move start time (46 samples)	Move start time (–25)	Move start time (–40.5)	Move start time (–84.9)
		DC shift (390–510)	DC shift (190–230)	DC shift (470–530)	DC shift (1,800–2,000)
		Time gain (start 86 lin 100 exp 5)	Gain (Start 17 lin 2.9 exp 1)	Gain (Start 51.8 lin 3.6 exp 0.5)	Gain (Start 92 lin 6.2 exp 0.13)
		(FIR)			

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 Table 5-2 and are also visible on the radargrams in Appendix 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 PDPP from RaaX was used.

4.3 Nonconformities

No nonconformities occurred during the logging of KFM11A in November 2006.

5 Results

The results from the BIPS measurements in KFM11A 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 KFM11A 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. It should be remembered that the images in Appendix 1 is 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. An overview of the borehole is given in Figure 5-1 below. Differences in data quality can be observed along the borehole. The data down to approximately 350 m shows good penetration compared to the rest of the hole. This is most probable due to less electrical conductivity of the water, or due to more suitable rock conditions.

A number of minor structures also exist, as indicated in Appendix 1. Often clusters of structures can be noticed, but often located so close to each other that it is impossible to distinguish one from the other. Larger structures parallel to the borehole, if present, are also indicated in Appendix 1. It should also be pointed out that an interpreted reflector always results in an intersection with the borehole (unless the reflector is strictly parallel to the hole). However, sometimes this intersection point is localized outside the range of the borehole.

KFM11A

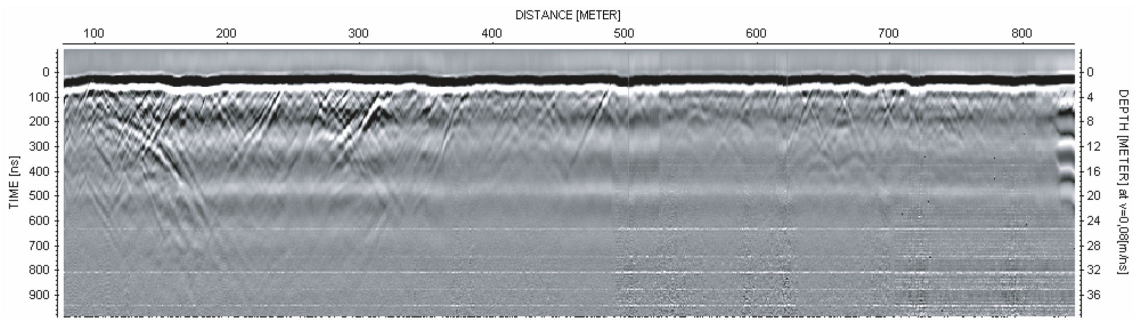


Figure 5-1. *An overview (20 MHz data) of the radar data for the borehole KFM11A. As seen, the radar penetration is slightly reduced from approximately 350 m borehole length.*

The data quality from KFM11A (as seen in Appendix 1) is satisfying to good, but in some parts of lower quality due to more conductive conditions. A electrical conductive environment causes an attenuation of the radar wave, which in turn decreases the penetration. This conductive environment of course also reduces the possibility to distinguish and interpret possible structures in the rock which otherwise could give a reflection.

This effect is also seen in the directional antenna, which makes it more difficult to interpret the direction to the identified structures.

As also seen in Appendix 1, the resolution and penetration of the radar waves depend on the antenna frequency used. Low antenna frequency gives less resolution but better penetration 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 Table 5-1 below the distribution of identified structures along the borehole are listed.

Table 5-2 summarises the interpretation of radar data from KFM11A. In the table the borehole length and intersection angle to the identified structures are listed.

As seen some radar reflectors in Table 5-2 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 5-2. This direction and the intersection angle are recalculated to strike and dip, also given in the tables below. The plane strike is the angle between the line of the plane's intersection with the surface and the Magnetic North direction. A strike of 0 degrees implies a dip to the east while a strike of 180 degrees implies a dip to the west (right-hand rule). The strike is measured clockwise and can vary from 0 to 359 degrees. The dip of the plane is the angle between the ground surface and the plane, and can vary from 0 to 90 degrees.

Observe that the interpretation of an undulating structure can result in several different angles and different intersection lengths. An example of this phenomenon is seen in Table 5-2 and Appendix 1: the reflectors named 216 and 216x most likely originates from the same geological structure.

Table 5-1. Identified structures as a function of borehole intersection length in KFM11A.

Length (m)	No. of structures
–50	2
50–100	14
100–150	25
150–200	20
200–250	18
250–300	16
300–350	18
350–400	7
400–450	15
450–500	11
500–550	8
550–600	12
600–650	12
650–700	15
700–750	17
750–800	11
800–	13

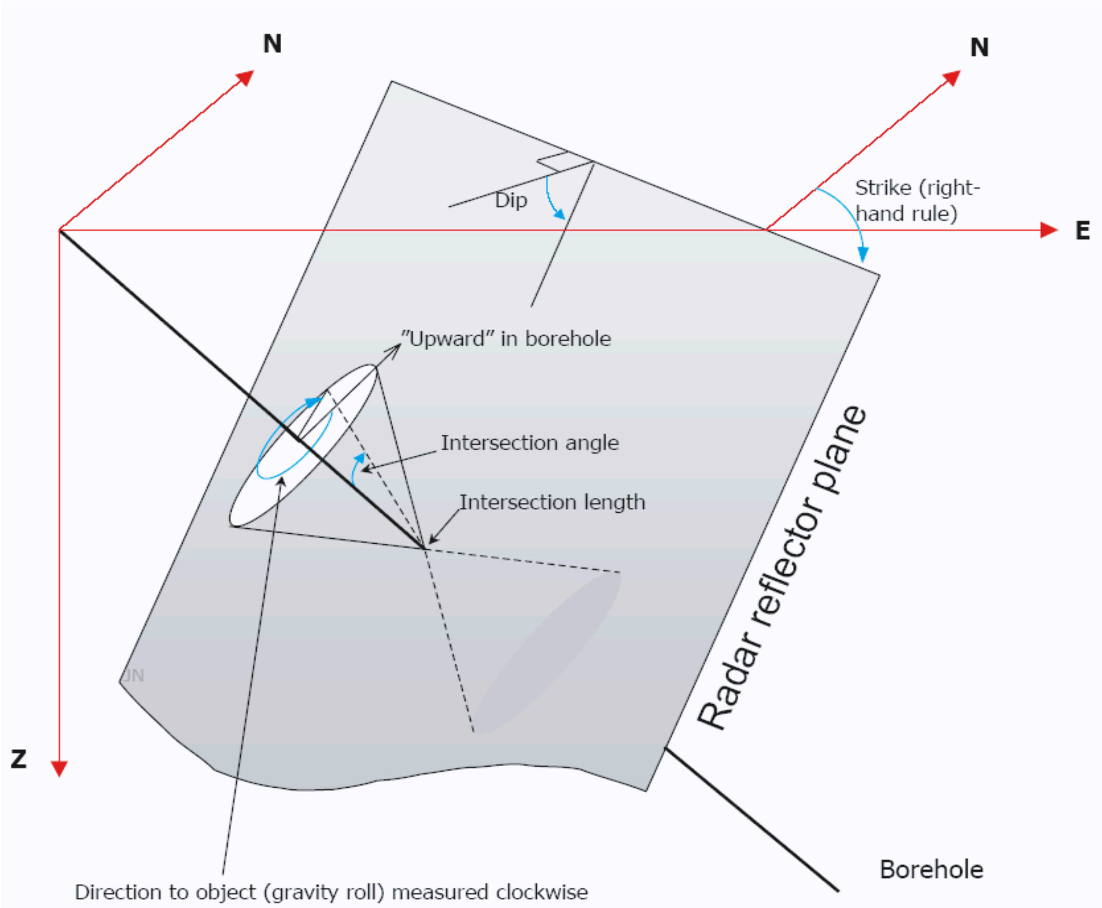


Figure 5-2. *Definition of the direction to a reflector (gravity roll) as presented in Table 5-2.*

Table 5-2. Interpretation of radar reflectors from the dipole antennas 250, 100 and 20 MHz in borehole KFM11A.

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site:	**Forsmark**
Borehole name:	**KFM11A**
Nominal velocity (m/µs):	**128.0**

Name	Intersection length	Intersection angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
216	23.4	10	66 ±	89	13	69	24
217	35.3	35					
217x	60.8	86					
225	61.9	17	285	82	60		
13	62.0	50					
218	63.7	37					
1	76.0	44					
2	81.3	55					
3	87.1	64	291 ±	48	89	36	200
4	91.0	46					
5	92.0	64					
226	92.3	40	90	56	198		
6	93.4	84					
7	95.6	42					

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site:	**Forsmark**
Borehole name:	**KFM11A**
Nominal velocity (m/μs):	**128.0**

Name	Intersection length	Intersection angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
17	98.6	60					
8	99.2	49					
9	100.3	58					
10	101.8	40					
216x	102.2	32					
11	102.7	67					
209	103.2	38					
10x	104.7	30					
207	105.7	69					
15x	106.1	55					
12	106.6	40	126	36	223		
224	108.2	31	21 ±	85	147	33	344
14	108.3	62					
15	109.6	42					
208	117.1	71					
16	120.6	39					
30	121.7	56					
18	123.5	38					
219	123.6	39					
19	126.8	35	357	81	127		
20	129.6	38					
21	131.6	37					
22	134.8	79					
23	141.6	35					
24	144.3	28					
25	145.5	30					
26	148.8	34					
27	151.1	32					
28	157.8	36					
29	157.8	31					
35	159.5	35					
32	159.9	27					
33	162.0	42					
31	165.6	44	129 ±	36	229	69	91
34	172.9	41					
39	174.6	60					
36	175.7	41	348	79	120		
38	179.1	39					
42	182.5	49					
43	183.1	59					
40	184.3	45					
41	189.2	43					
45	189.6	33					
47	192.1	61					

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site:	**Forsmark**
Borehole name:	**KFM11A**
Nominal velocity (m/μs):	**128.0**

Name	Intersection length	Intersection angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
48	192.7	35					
44	193.4	68	180 ±	11	130	47	130
221	194.4	69					
210	211.6	44					
46	212.3	69					
50	214.6	38	42 ±	74	163	34	19
51	216.6	36					
52	219.6	34					
54	222.4	33					
53	222.5	41					
57	224.1	29					
49	225.4	42					
56	227.0	29					
55	228.6	30					
58	231.5	36					
59	235.2	37					
211	237.1	42					
61	239.6	36	147	30	252		
60	241.2	43					
63	244.9	40					
62x	248.9	47					
62	250.1	34					
220x	250.6	36	132	39	237		
65	251.9	45	358	46	59		
66	256.1	42					
220	256.9	29	129	47	241		
67	257.0	36	270 ±	60	60	60	201
68	264.1	39					
69	265.6	33	93	62	206		
70	267.5	33					
71	270.3	36					
72	281.5	42	309	71	93		
77	282.1	37					
73	284.9	33					
74	286.6	36	345	82	119		
75	291.0	35					
76	293.0	34					
82	300.3	44					
78	303.2	26	18	89	146		
79	304.5	26					
80	306.2	37					
212	309.5	38					
80x	310.5	27	315	85	92		
83	311.3	39	339	80	115		

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site:	**Forsmark**
Borehole name:	**KFM11A**
Nominal velocity (m/μs):	**128.0**

Name	Intersection length	Intersection angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
81	311.8	31					
85	318.0	39					
84	320.9	39					
86	324.9	42	144 ±	30	246	76	103
87	327.6	41	195	19	347		
88	335.9	34					
89	336.5	42					
91	337.4	48	324	68	106		
90	338.4	37	240	47	35		
92	342.2	42					
93	346.1	35					
95	362.2	60					
94	364.1	59					
98	367.7	54					
96	368.5	48					
97	374.4	51					
99	387.3	53					
100	398.5	54					
101	402.1	43					
102	404.3	42					
103	408.7	31					
104	409.0	41					
105	411.0	29					
106	415.2	42					
108	423.9	52	165 ±	12	258	68	121
107	425.3	72					
213	426.1	54					
110	433.3	39					
109	433.8	44	153	24	254		
111	437.7	38					
112	439.1	57					
113	443.0	60					
114	448.3	88					
116	451.6	60					
115	454.3	43					
117	455.1	61					
227	457.0	20	348	79	299		
118	461.7	48					
222	464.1	29					
120	475.1	60					
119	475.8	25					
122	482.7	67					
121	491.4	22					
123	497.8	48	201	16	11		

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site:	**Forsmark**
Borehole name:	**KFM11A**
Nominal velocity (m/μs):	**128.0**

Name	Intersection length	Intersection angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
124	501.7	47					
128	520.3	65					
127	525.8	44					
129	528.3	62					
125	536.8	36					
126	539.6	39	303	72	86		
130	548.0	55					
138	548.0	39					
136	561.3	44					
131	563.4	45					
132	564.7	45					
133	567.8	40					
134	574.9	47					
135	579.5	38	51	77	168		
137	581.9	39					
139	583.8	40					
140	588.8	43					
141	591.6	48	96	49	188		
142	593.9	48					
143	599.4	35					
144	603.5	32					
145	605.4	50					
146	609.3	51					
147	612.9	50					
148	619.8	56					
150	622.8	47					
149	624.6	47					
151	627.5	51	144	21	204		
152	633.3	58					
153	640.2	57					
154	643.0	66					
155	648.1	53					
156	652.9	54	210	17	54		
157	654.5	60					
158	657.6	54					
159	659.0	64					
160	662.0	55					
161	664.9	49					
214	668.2	56					
162	671.2	64					
163	678.3	56	189	6	29		
223	680.6	46					
164	684.6	55	120 ±	33	184	58	93
165	685.9	56					

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site:	**Forsmark**
Borehole name:	**KFM11A**
Nominal velocity (m/μs):	**128.0**

Name	Intersection length	Intersection angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
166	689.6	64					
215	691.2	64					
167	693.2	65	129 ±	27	172	55	102
168	701.1	72					
170	701.7	54					
169	702.7	51					
171	715.4	48					
172	718.2	62					
173	718.9	50					
174	717.5	45					
206	717.9	42					
172x	719.6	43	216	26	26		
175	721.1	60					
176	728.4	64					
179	730.5	58	27	67	141		
177	735.9	56					
178	739.3	48					
180	744.2	60					
183	746.4	49	45	68	153		
181	747.2	71					
182	750.7	61					
184	760.2	60					
185	764.0	60					
186	773.9	66	141	23	165		
187	778.9	59					
205	780.6	63					
188	782.0	48					
189	783.8	49					
228	787.4	38	18 ±	88	140	20	351
190	787.6	57					
191	792.9	56					
192	800.9	46					
193	801.5	55	201	13	33		
198	809.1	42	201 ±	17	8	83	141
194	811.6	49					
196	814.7	34	237	40	40		
195	817.1	42					
197	823.4	53					
199	825.9	53					
200	827.4	56					
201	833.4	45					
203	838.6	58					
202	844.0	51					
204	852.4	75					

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

Finally, the structures considered as the most important (clear in the radargram, identified with several antenna frequencies, stretching out far from the borehole wall etc) are listed in Table 5-4.

Observe that it can be very difficult to classify different structures in an objective manner along a borehole. This is due to the fact that the water quality (the conductivity) amongst other parameters varies along the borehole length. This variation affects the results of the radar logging, by for instance attenuating the radar waves differently. Also the intersection angle of the identified structures affects the amplitude on the resulting radargram. A small angle will most often cause larger amplitude than a large angle, and by that a more clear structure.

Table 5-3. Borehole length intervals in KFM11A with decreased amplitude for the 250 MHz antenna.

Length (m)	Length (m)
75	495–505
85–90	520–525
105–125	540
130	560–565
150–170	590–595
175–185	600
190	620–630
220	650–655
250–255	665
260	675–685
325–330	700–705
345–350	715–725
355–380	780–805
390	820
405–470	

Table 5-4. Some important structures in KFM11A.

Borehole	KFM11A
Structures	5, 10, 10x, 11, 15, 15x, 19, 26, 36, 67, 78, 80, 80x, 81, 7, 99, 123, 156, 170, 172, 198, 216, 216x, 220, 220x and 223

5.2 BIPS logging

The BIPS pictures are presented in Appendix 2.

To get the best possible length 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 are visible on the BIPS screen. The recorded length is adjusted to these visible marks.

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 in the campaign. The resulting images displayed no difference regarding the colours and focus of the images. The results of the test logging were included in the delivery of the field data and are also presented in Figure 4-3 in this report.

Values for the inclination and azimuth of the boreholes, presented in this report, are only preliminary.

Two logging runs have been performed in KFM11A. The first run was made during the drilling phase and this logging down to 250 metres showed medium quality images. The second run from 72 metres down to 848 metres showed improved image quality, although the quality was not perfect. The reason for this was mud in the water and mud that covered the lowermost part of the borehole wall. Also a partly discoloring of the walls from the drilling made the logging problematic.

To get a better understanding of the quality of the orientation of the images, a comparison between the probe orientation in two runs is shown in Table 5-5, utilizing features that can be clearly identified on the plots from both runs. The table shows examples of differences in the orientation of the probe ("Gravity Roll") between the two runs, and gives an idea of the uncertainties involved. Figure 5-3 illustrates the comparison. The direction values in the table are measured on a high-resolution plot from the lowermost point of the borehole wall (leftmost part of plots in Figure 5-3) to the actual feature.

Table 5-5. Differences in probe orientation between two runs in KFM11A.

Borehole length (m)	Run 1 Direction (°)	Run 2 Direction (°)	Difference (°)
74.8	185.0	188.7	3.7
90.3	64.6	68.1	3.5
93.8	279.1	282.6	3.5
111.9	249.0	250.3	1.3
129.8	338.5	337.2	–1.3
130.3	143.4	144.2	0.8
154.9	192.1	192.4	0.3
178.4	329.9	332.0	2.1
194.9	153.5	149.9	–3.6
216.2	290.4	289.1	–1.3
219.4	283.5	282.6	–0.9
230.8	134.0	133.4	–0.6
235.6	249.6	250.3	0.7

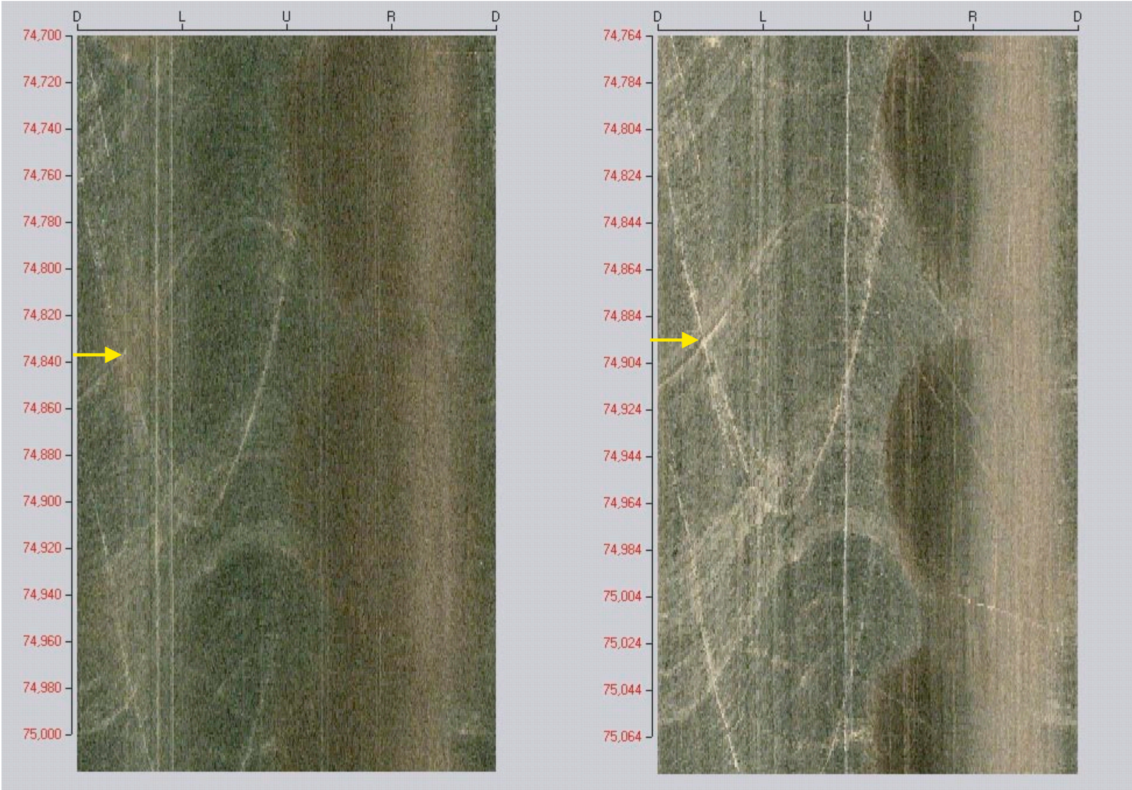


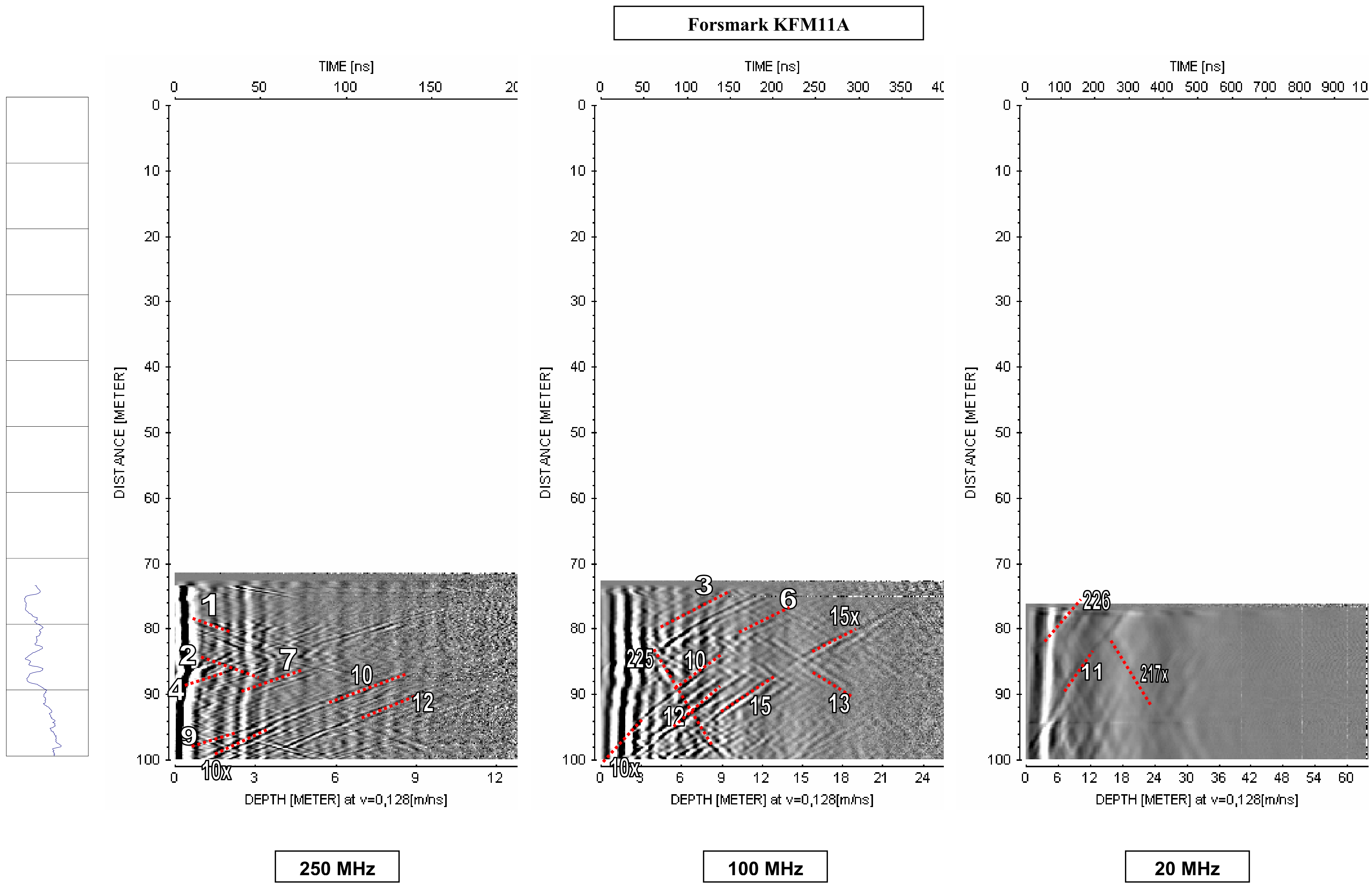
Figure 5-3. *Example of a comparison of the orientation of the BIPS-images between run 1 (left) and run 2 (right). The feature (an intersection between two planes) is marked with an yellow arrow.*

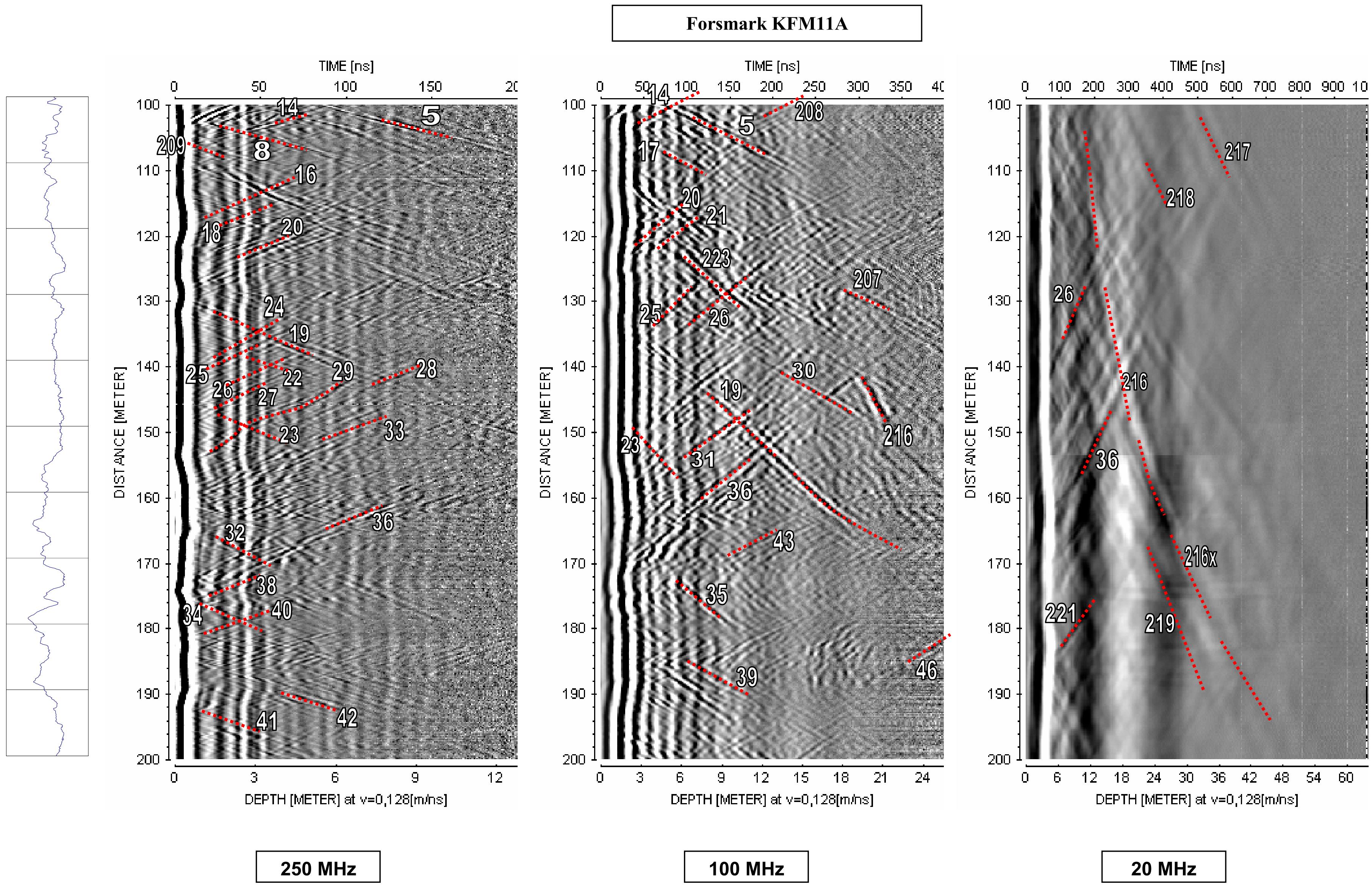
References

/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.

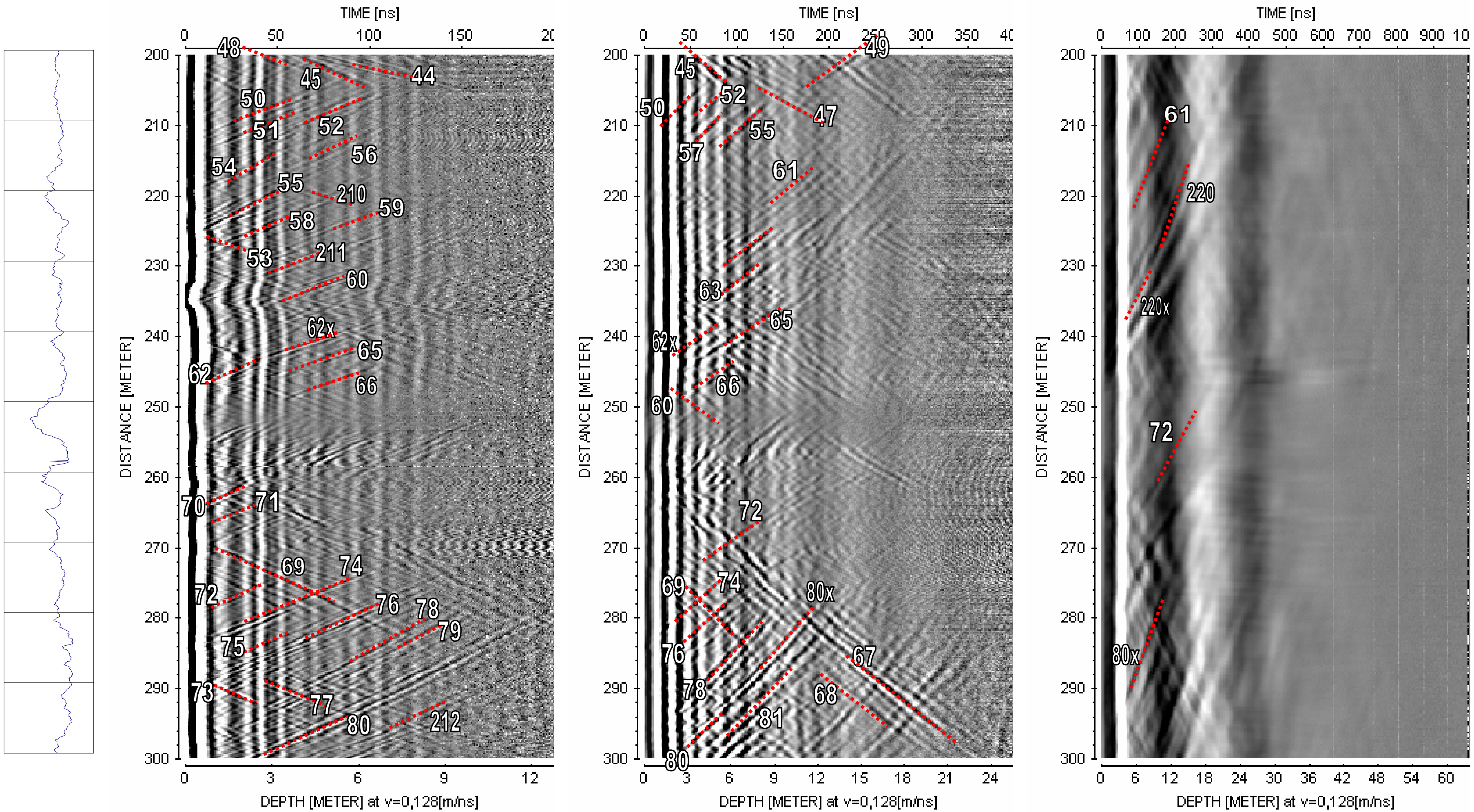
Appendix 1

Radar logging in KFM11A. 70 to 840 m. Dipole antennas 250, 100 and 20 MHz


Forsmark KFM11A
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128[m/ns]
1
2
4
7
9
10x
10
12
3
6
15x
225
15
13
226
11
217x
250 MHz
100 MHz
20 MHz

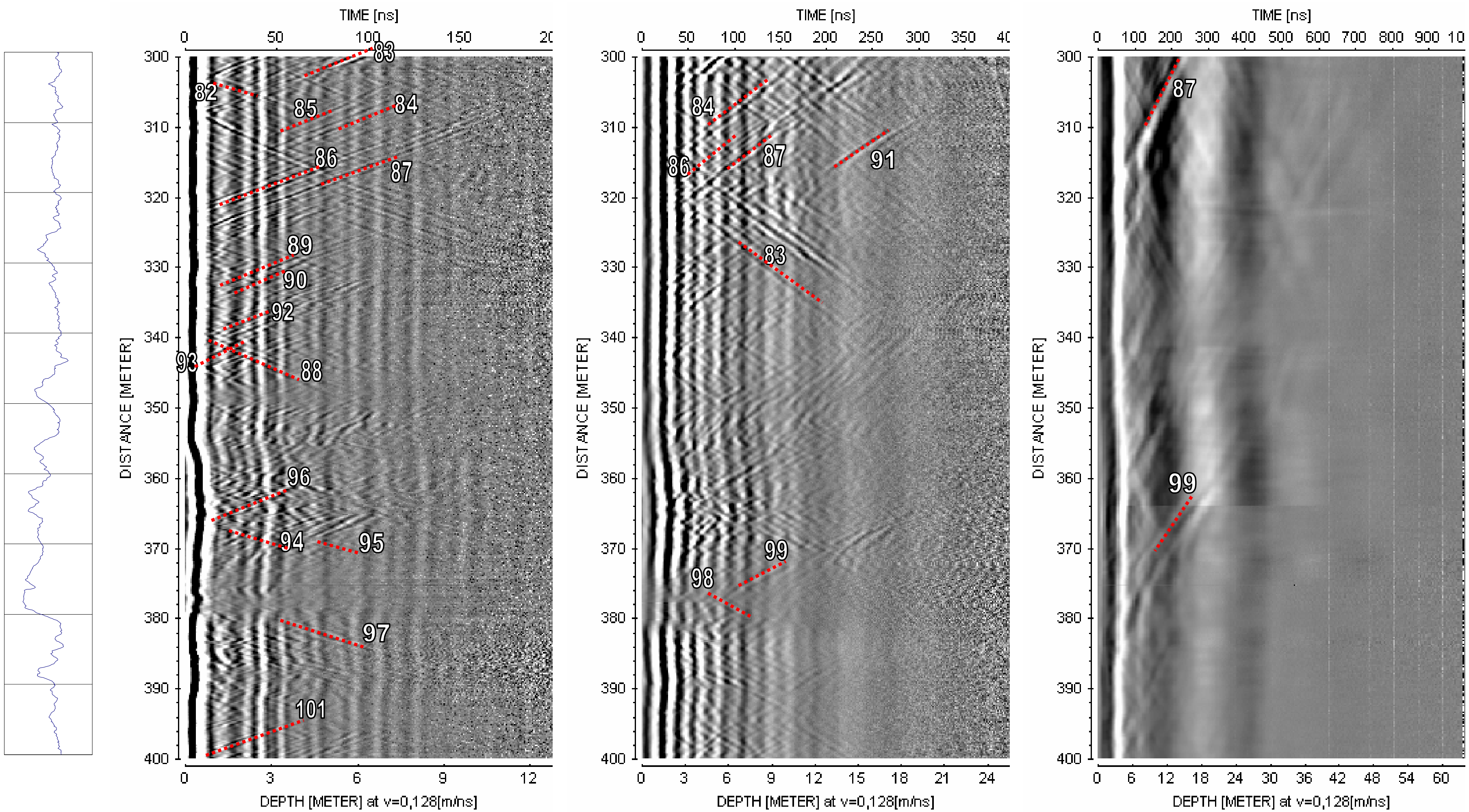

Forsmark KFM11A
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128[m/ns]
250 MHz
100 MHz
20 MHz

Forsmark KFM11A



250 MHz **100 MHz** **20 MHz**

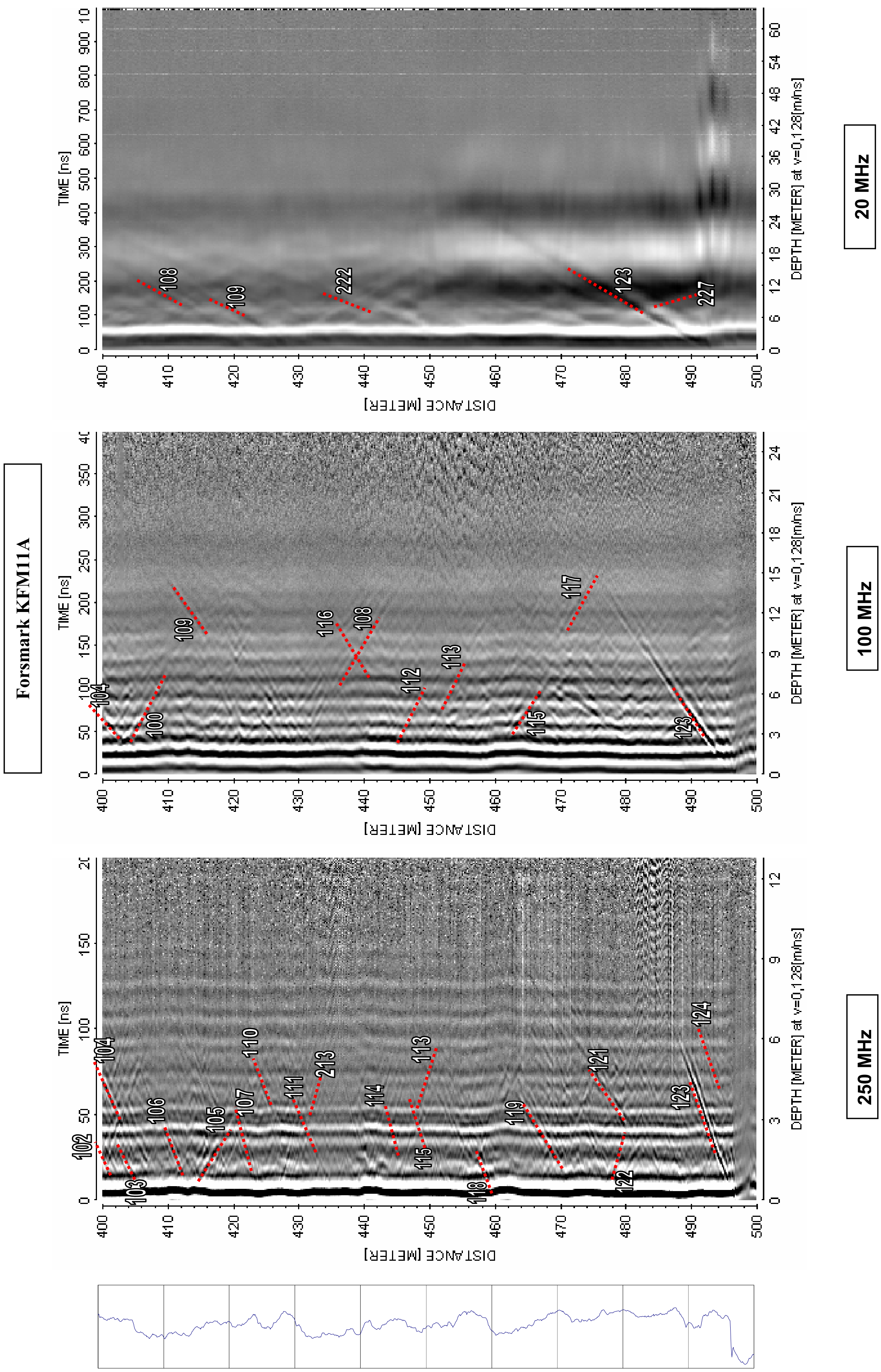
Forsmark KFM11A

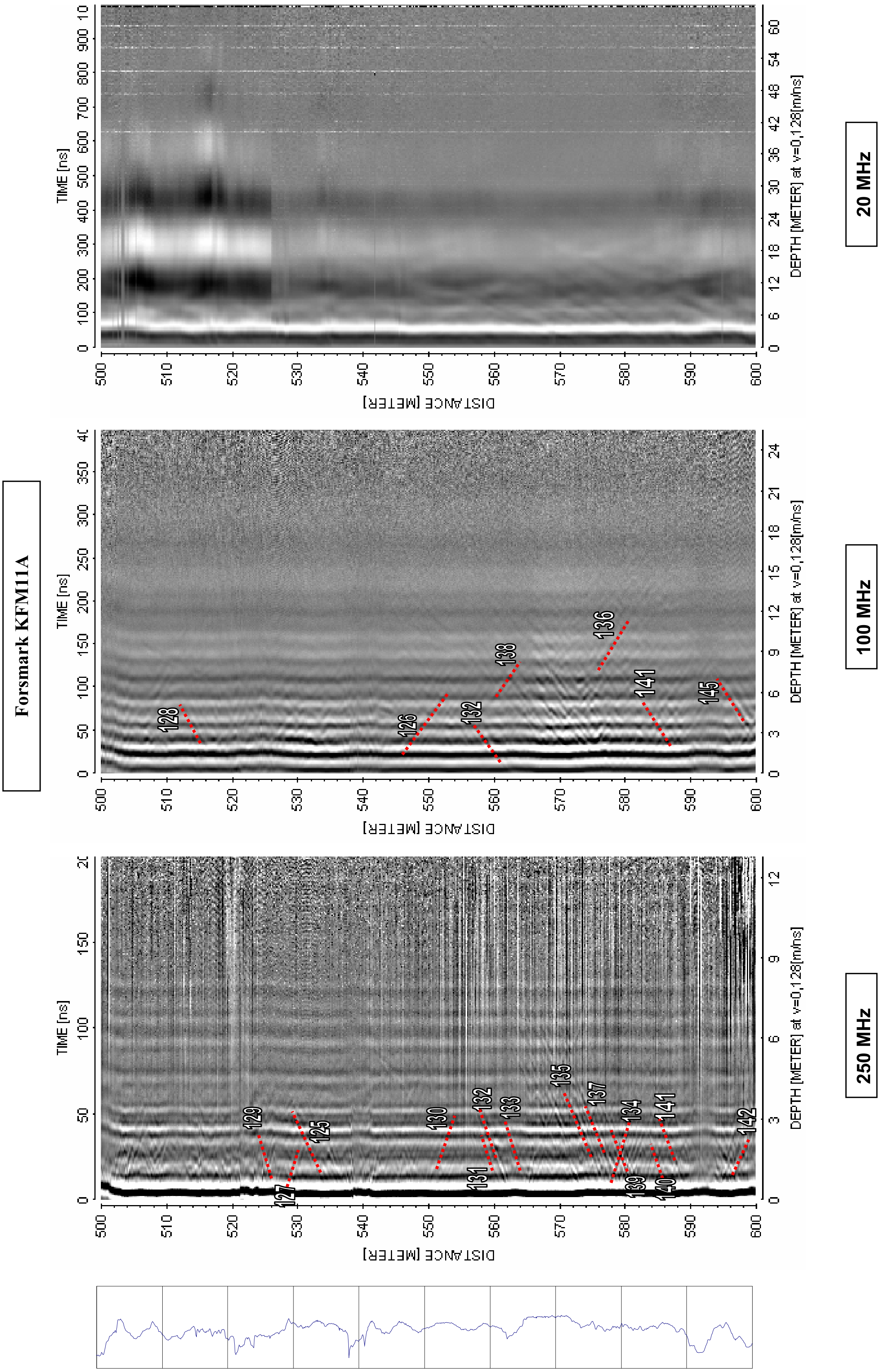


250 MHz

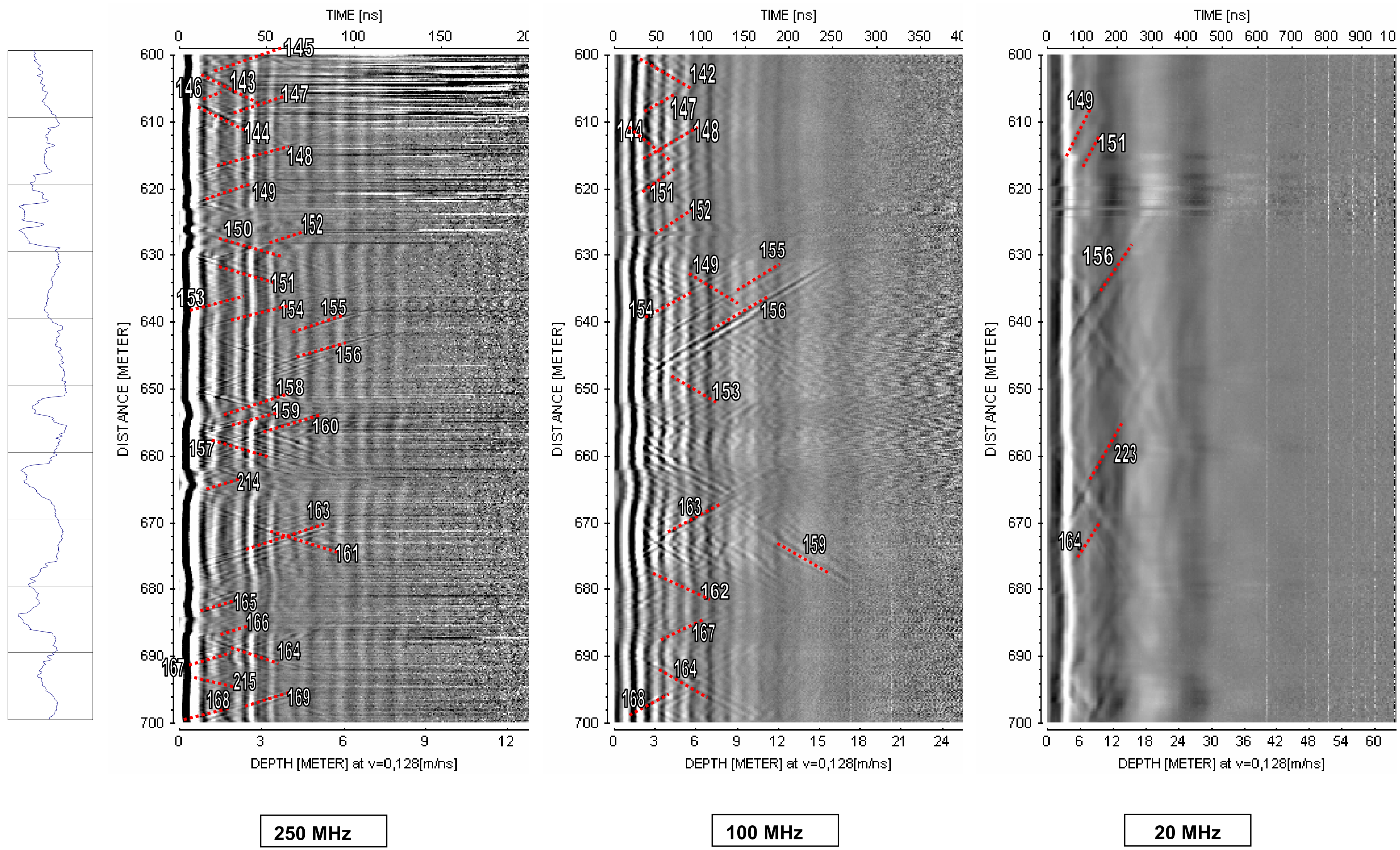
100 MHz

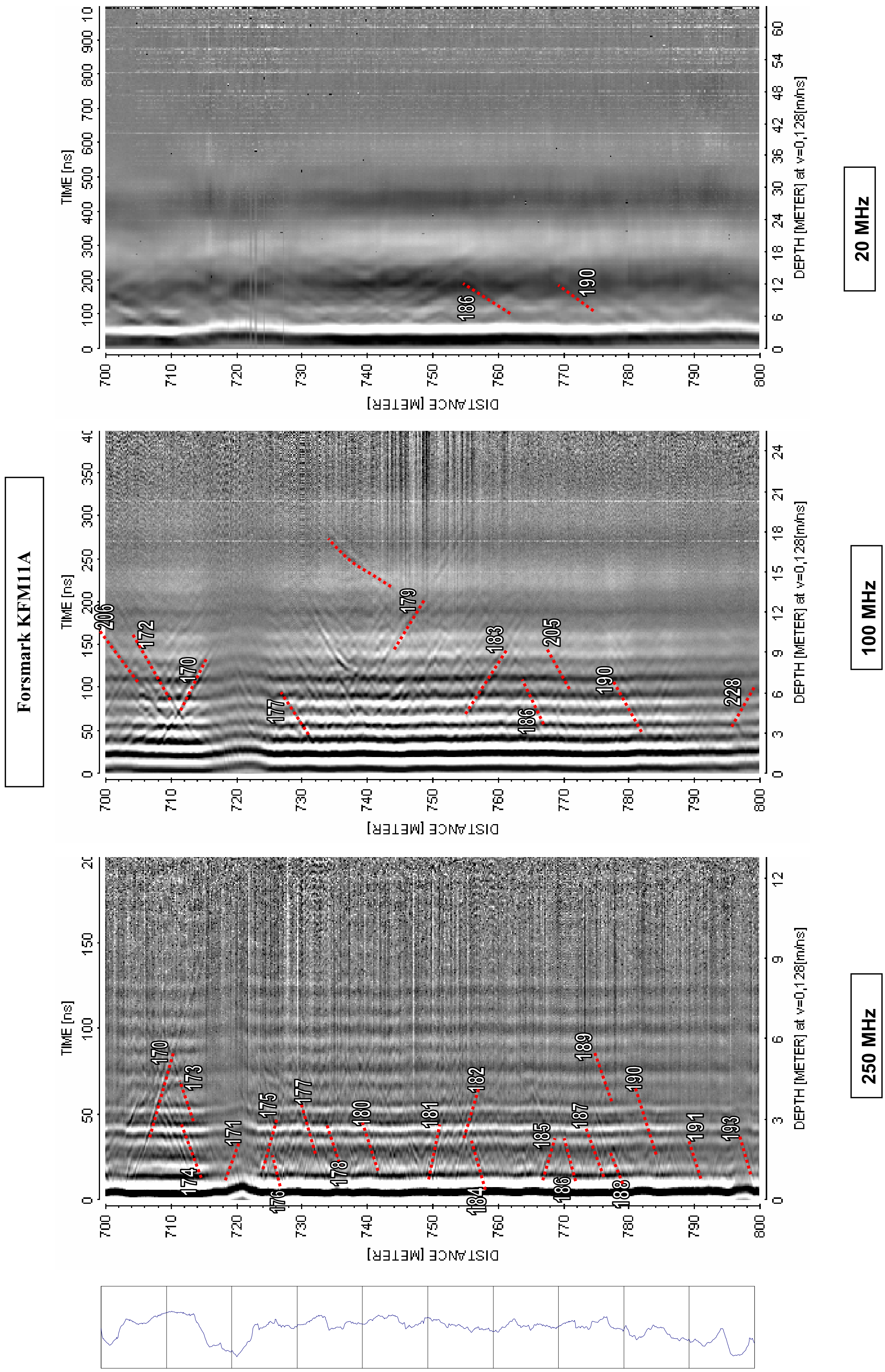
20 MHz


Forsmark KFM11A
250 MHz
100 MHz
20 MHz
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128[m/ns]


Forsmark KFM11A
250 MHz
100 MHz
20 MHz
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128[m/ns]
129
127
125
130
132
131
133
135
137
134
139
140
141
142
128
126
138
136
145

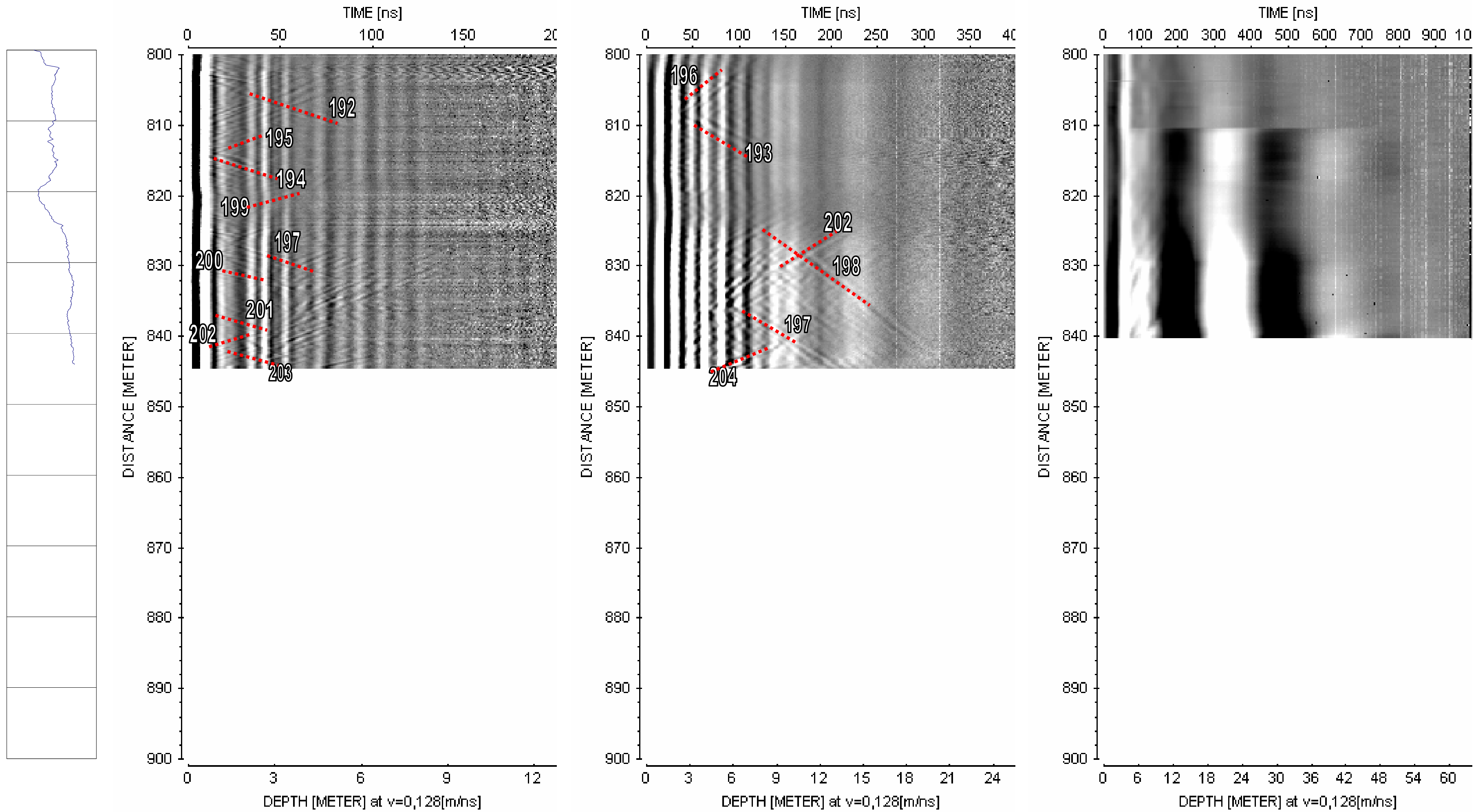
Forsmark KFM11A





Forsmark KFM11A
250 MHz
100 MHz
20 MHz
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128[m/ns]

Forsmark KFM11A



250 MHz

100 MHz

20 MHz

Appendix 2

BIPS logging in KFM11A. 72 to 847 m

Project name: Forsmark

Image file	: c:\work\r5588k~1\bips\bipslo~1\kfm11a-1.bip
BDT file	: c:\work\r5588k~1\bips\bipslo~1\kfm11a-1.bdt
Locality	: FORSMARK
Bore hole number	: KFM11A
Date	: 06/11/24
Time	: 13:03:00
Depth range	: 72.000 - 848.035 m
Azimuth	: 40
Inclination	: -61
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	: 40
Color	: +0 +0 +0

Project name: Forsmark
Bore hole No.: KFM11A   Azimuth: 40   Inclination: -61

Depth range: 60.000 - 80.000 m

D L U R D

60.000
60.000

61.000
61.000

62.000
62.000

63.000
63.000

64.000
64.000

65.000
65.000

D L U R D

65.000
65.000

66.000
66.000

67.000
67.000

68.000
68.000

69.000
69.000

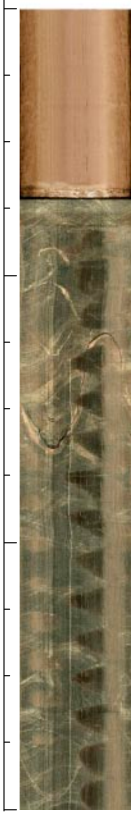
70.000
70.000

D L U R D

70.000
70.000

71.000
71.000

72.000
72.000



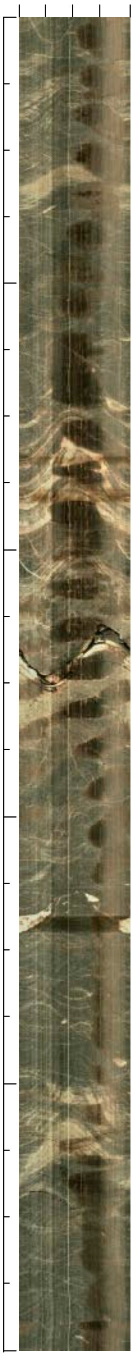
73.000
73.001

74.000
74.003

75.000
75.004

D L U R D

75.000
75.004



76.000
76.006

77.000
77.007

78.000
78.009

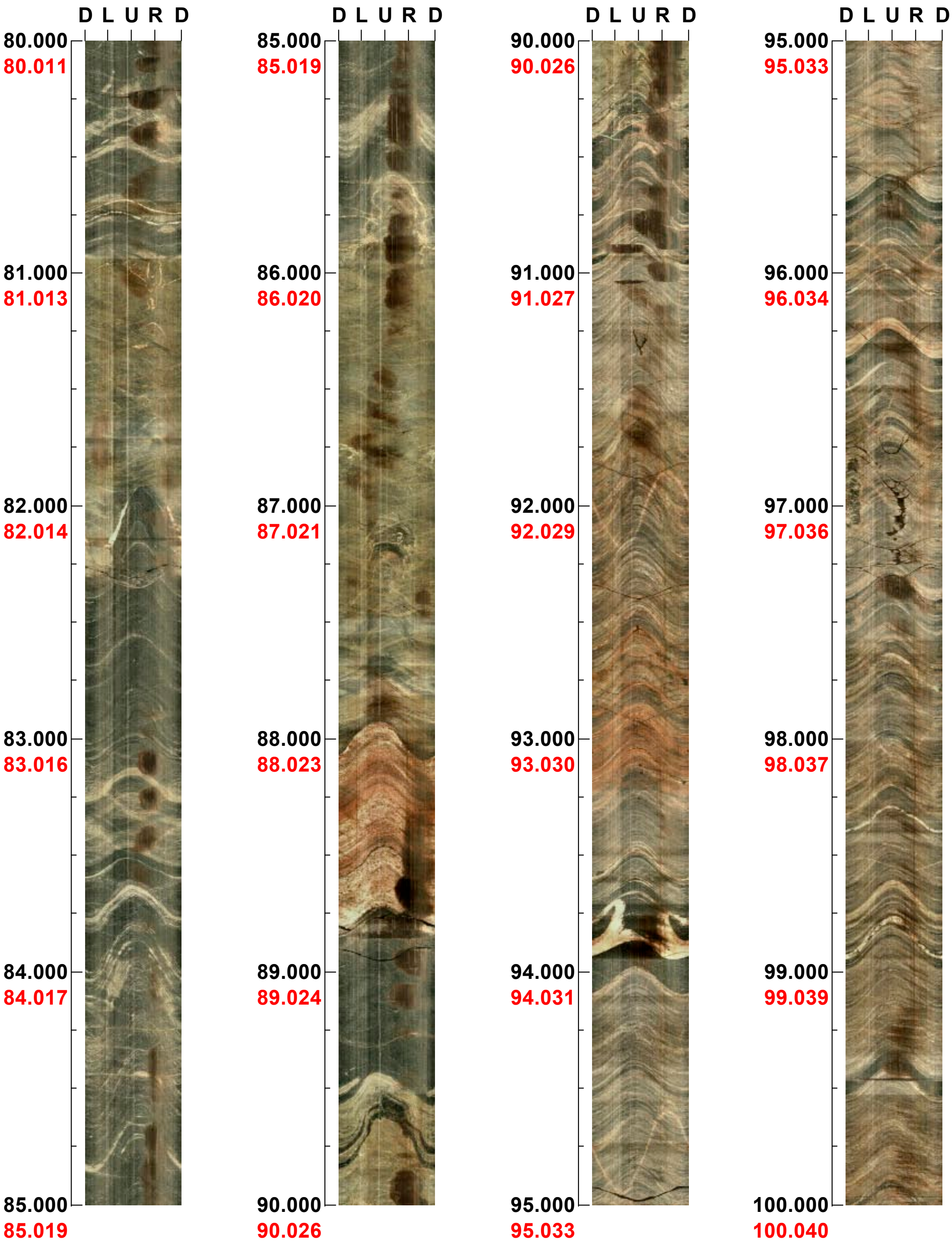
79.000
79.010

80.000
80.011

(1 / 26)   Scale: 1/25   Aspect ratio: 175 %

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

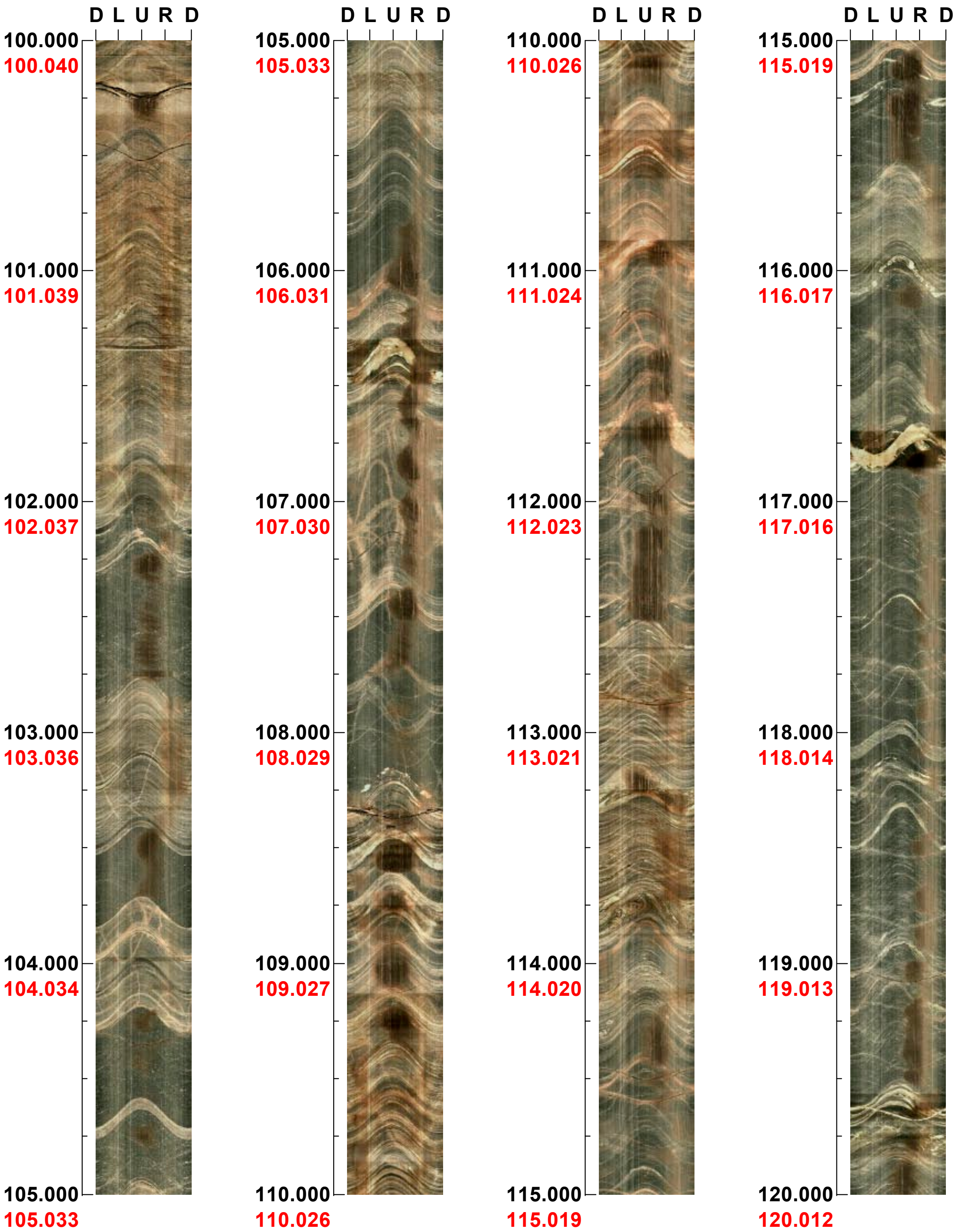
Depth range: 80.000 - 100.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A Azimuth: 40 Inclination: -61

Depth range: 100.000 - 120.000 m

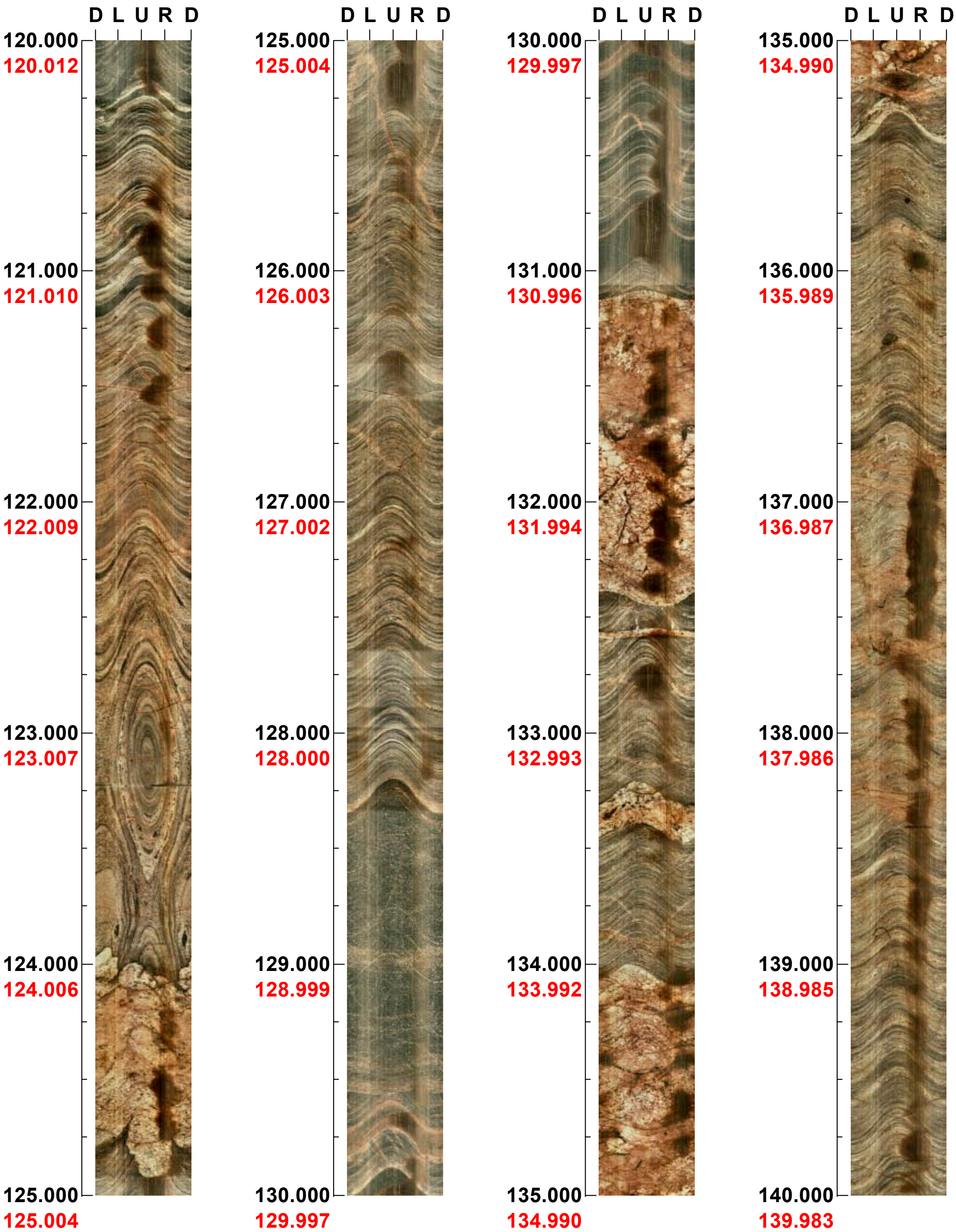


(3 / 26) Scale: 1/25 Aspect ratio: 175 %

Project name: Forsmark

Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

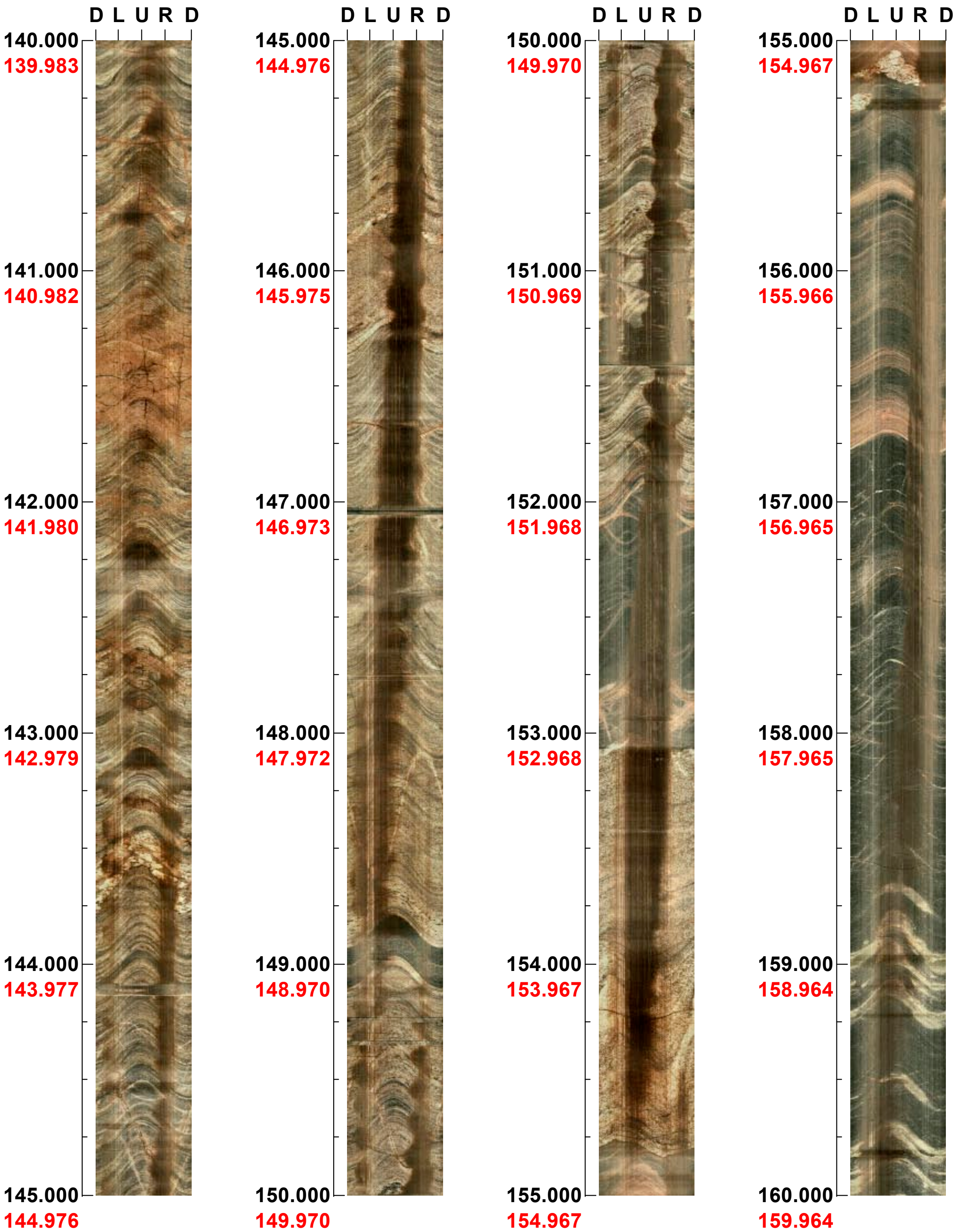
Depth range: 120.000 - 140.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

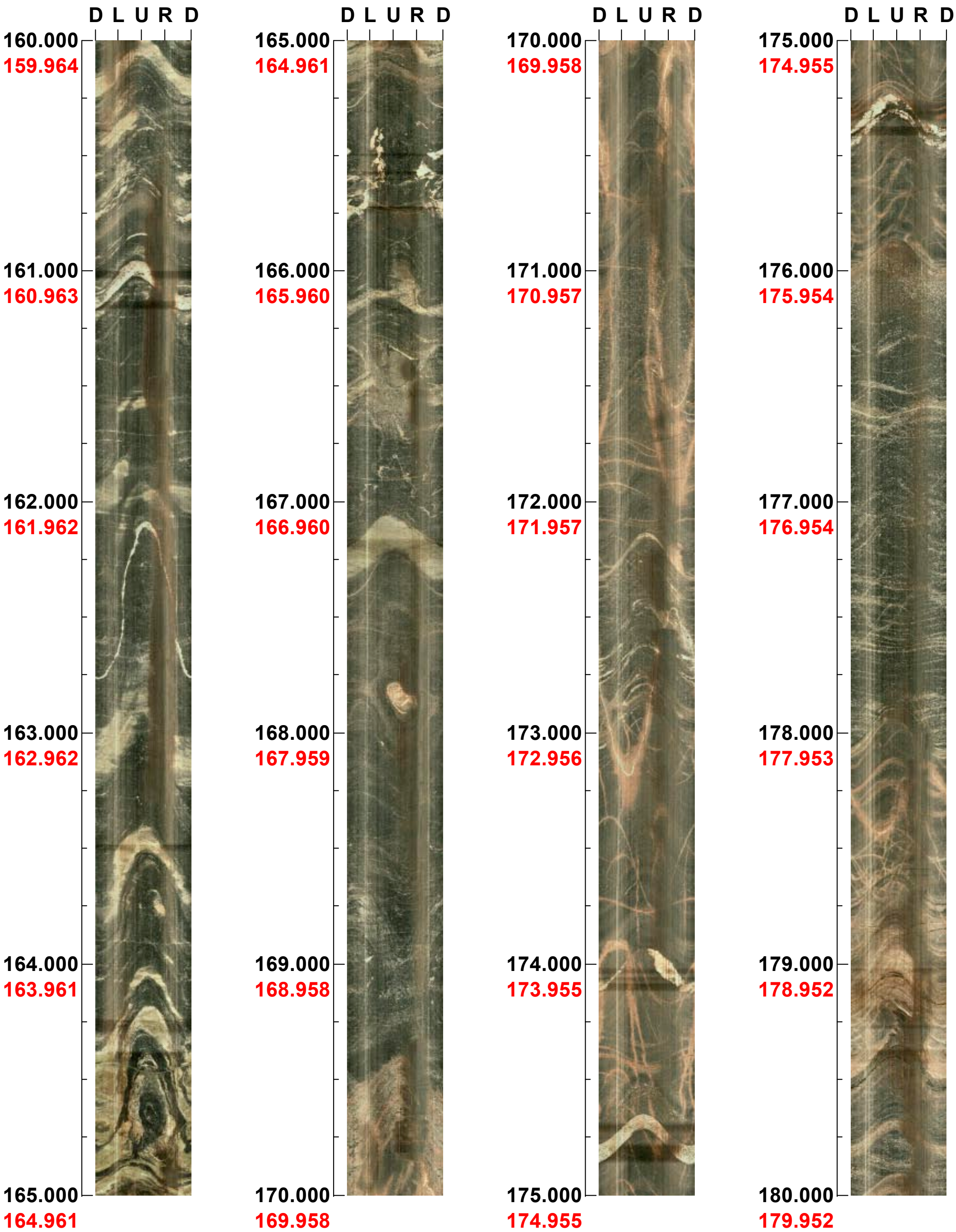
Depth range: 140.000 - 160.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 160.000 - 180.000 m

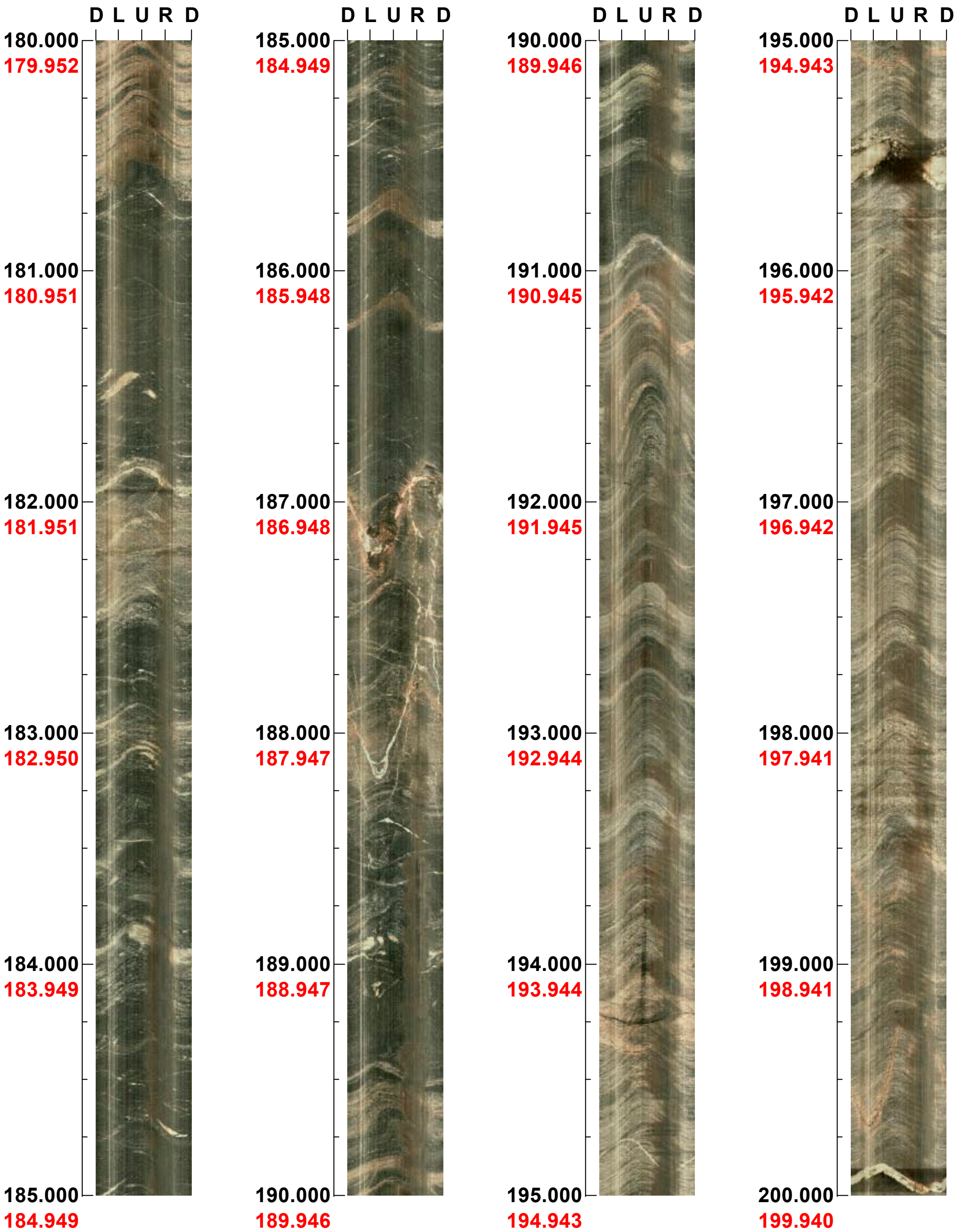


(6 / 26) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Forsmark

Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

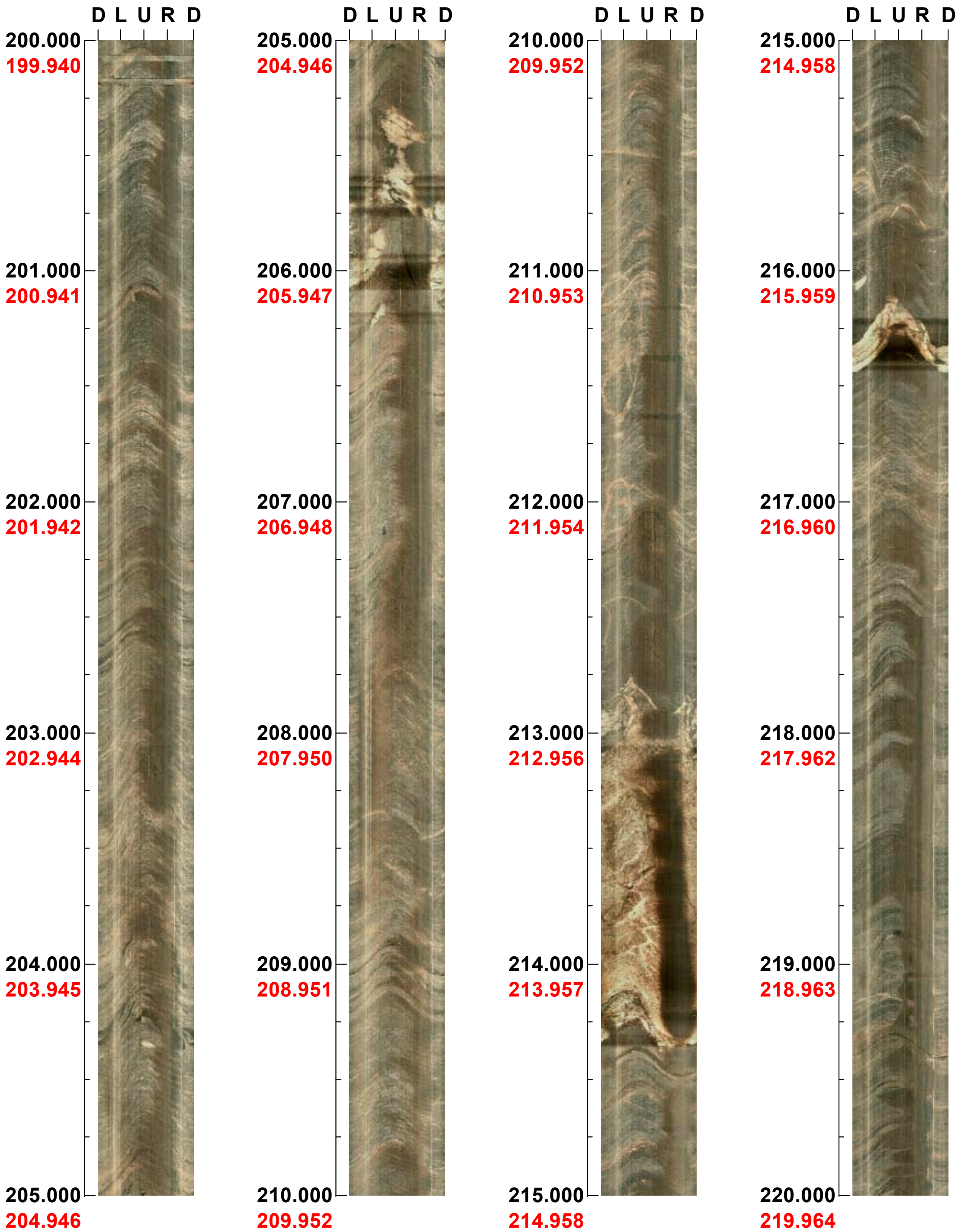
Depth range: 180.000 - 200.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 200.000 - 220.000 m



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

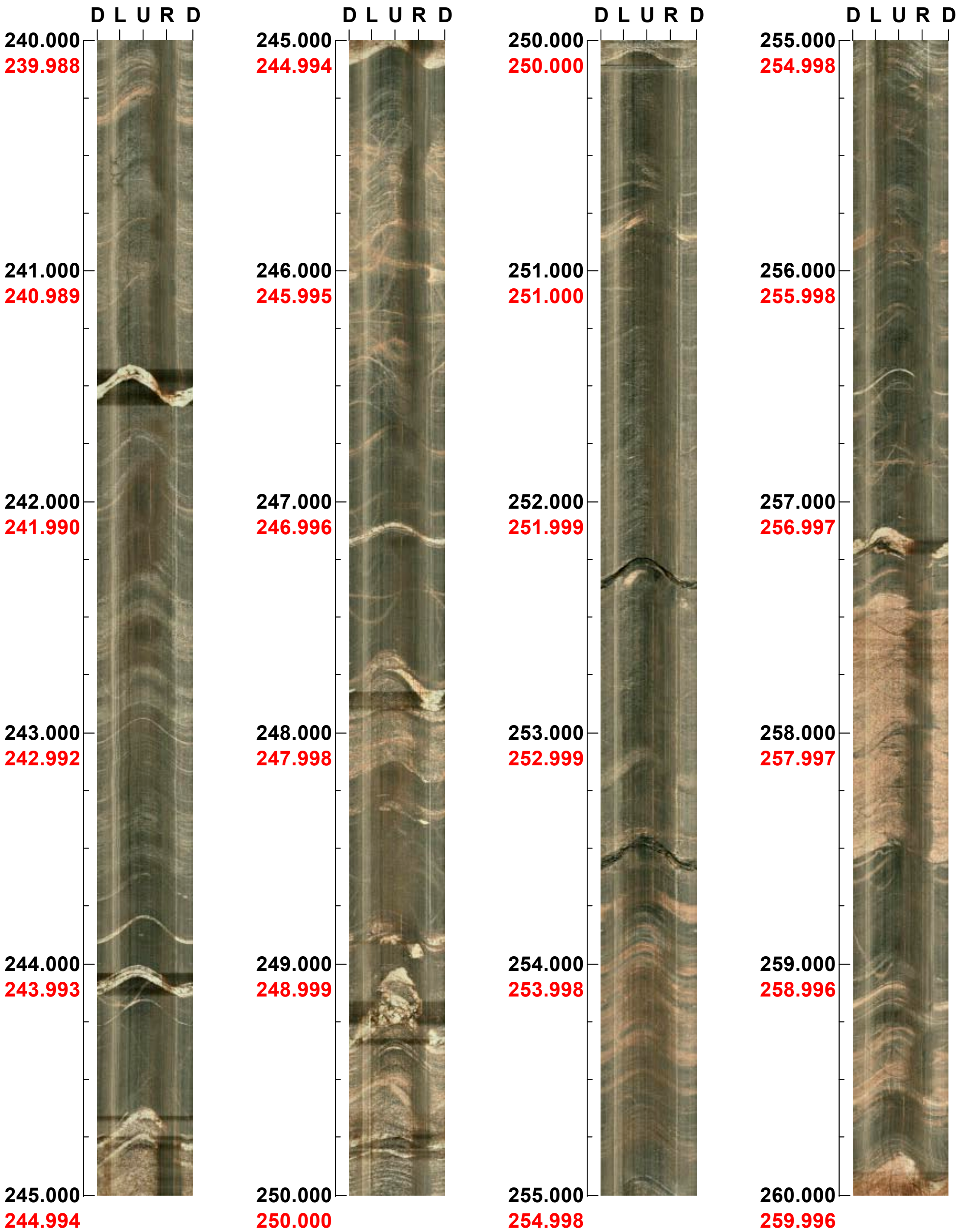
Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 220.000 - 240.000 m

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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

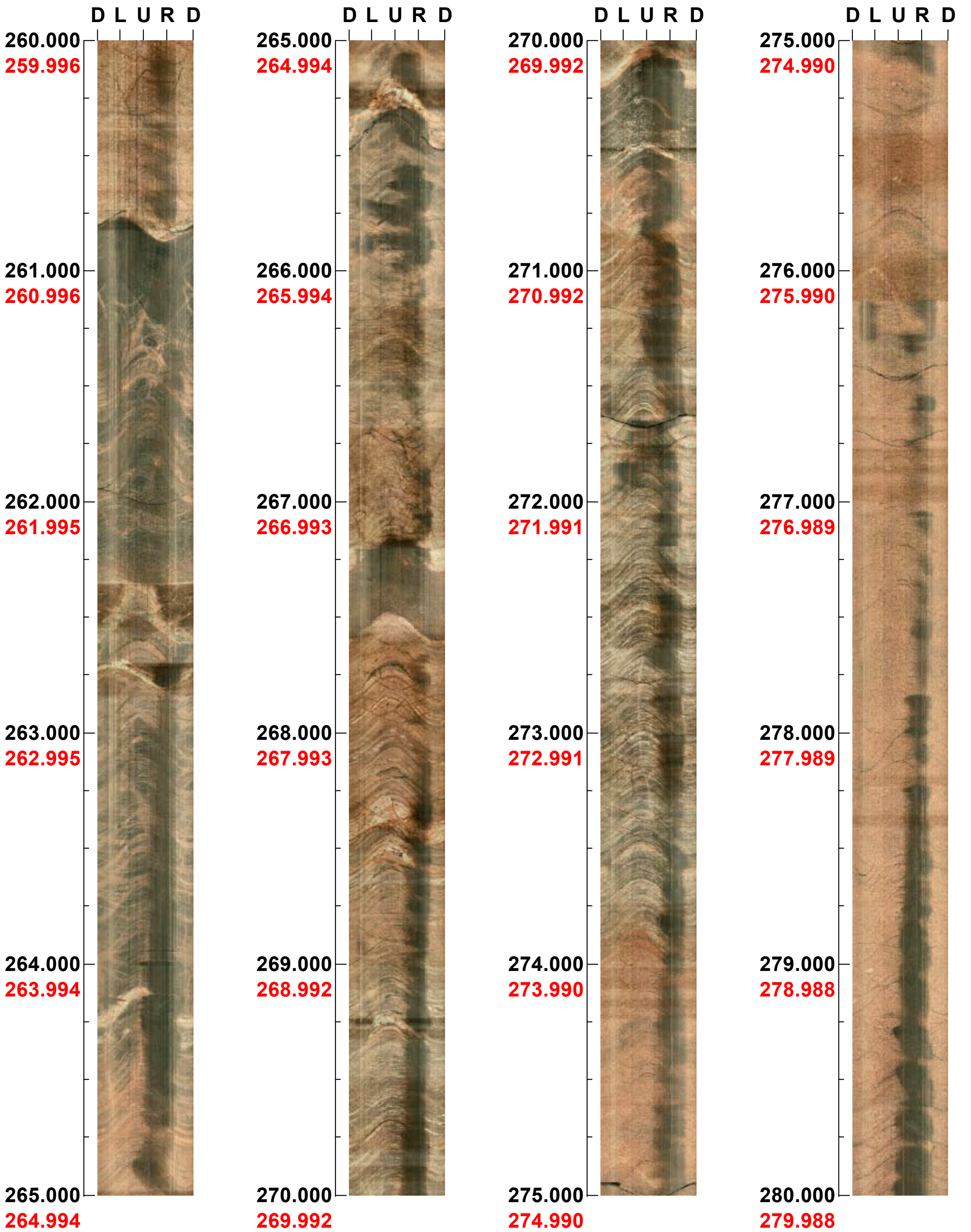
Depth range: 240.000 - 260.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

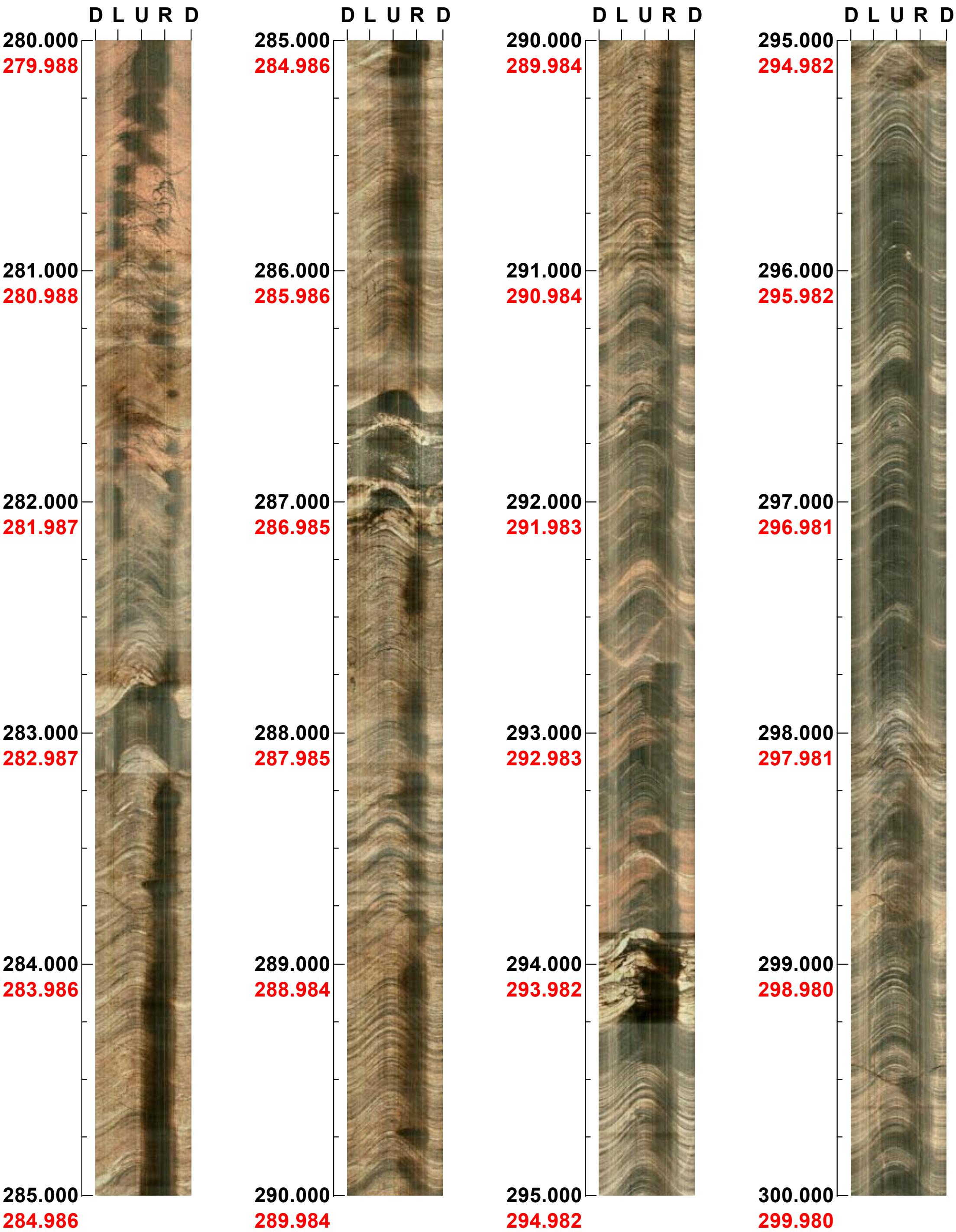
Depth range: 260.000 - 280.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

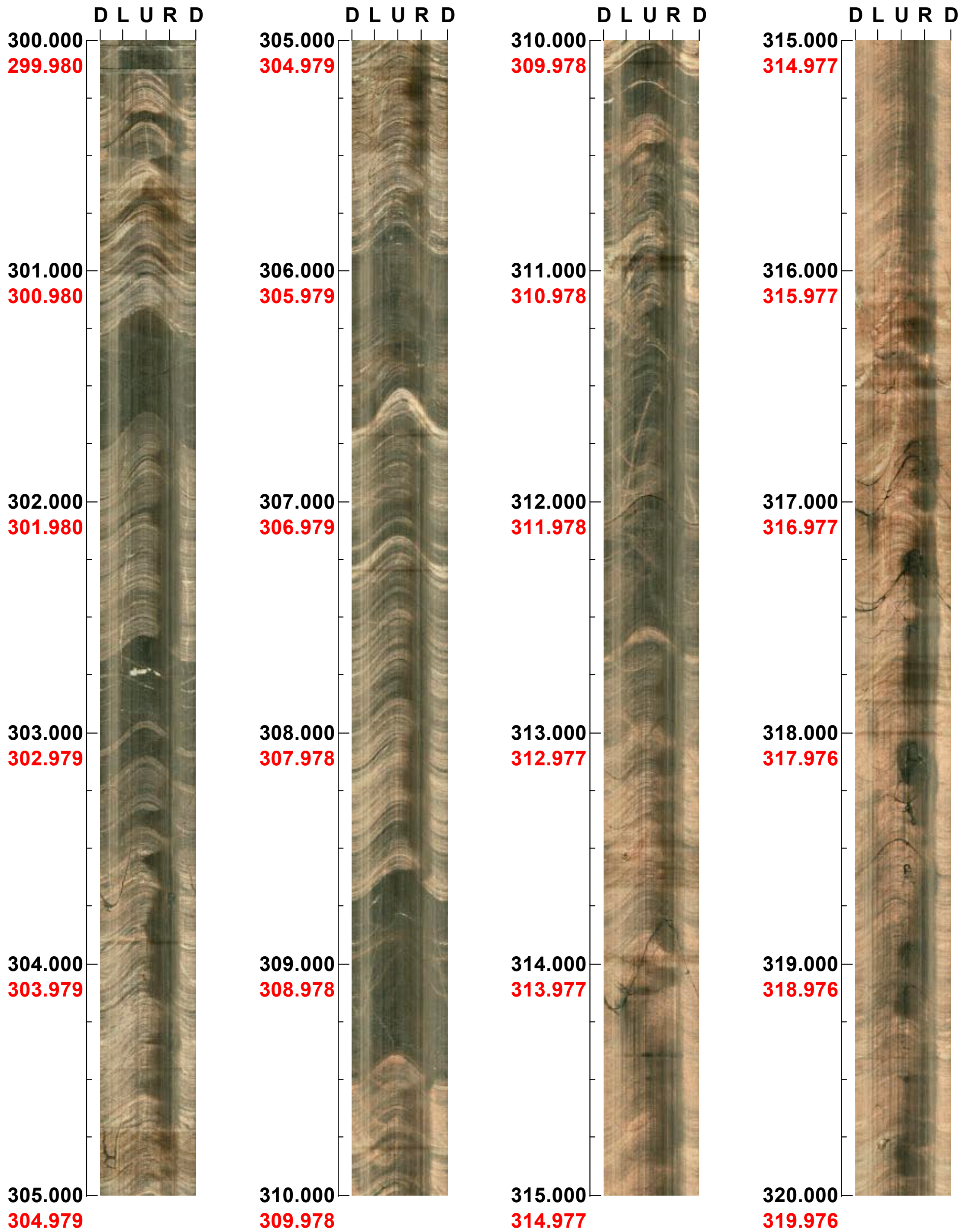
Depth range: 280.000 - 300.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 300.000 - 320.000 m

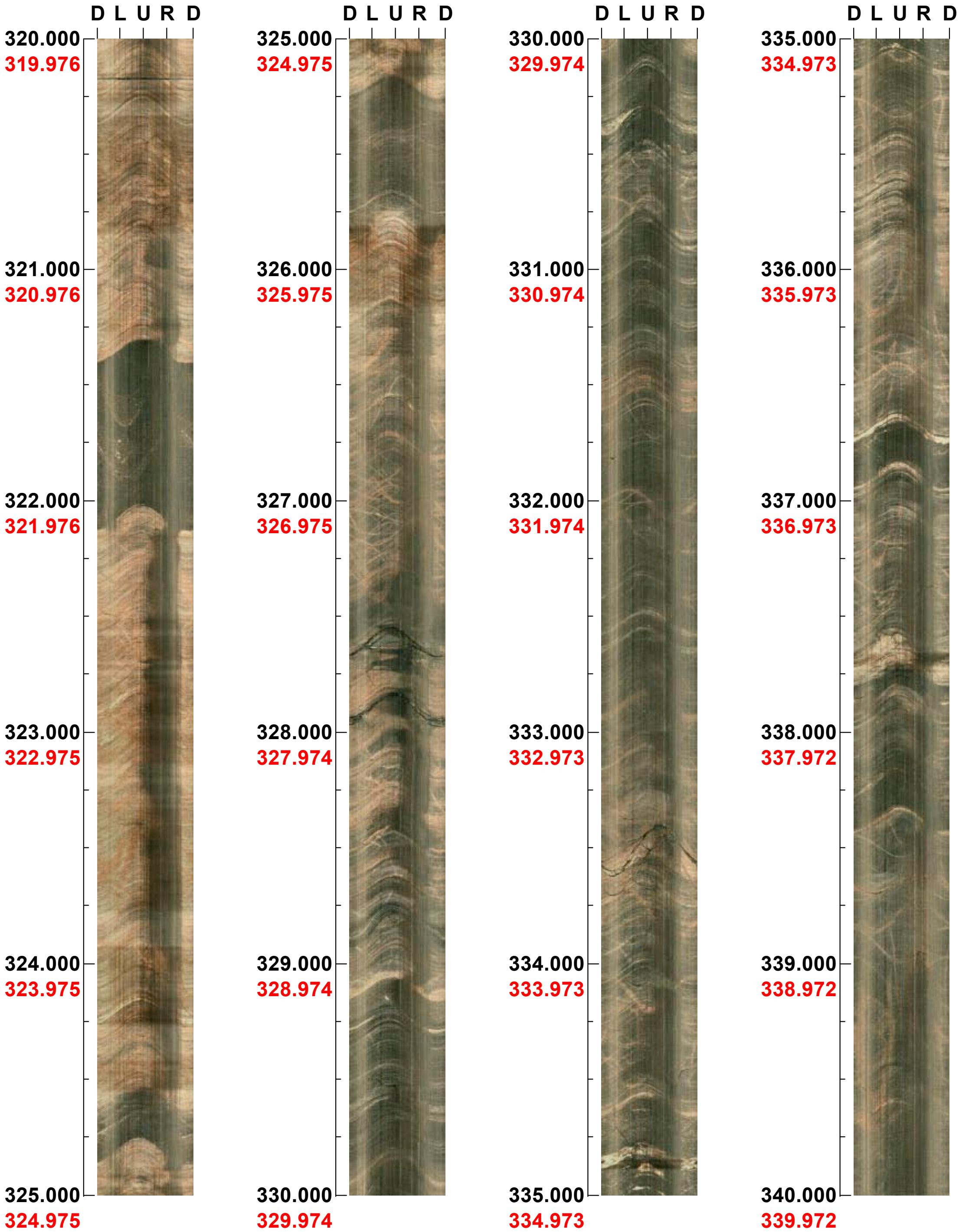


(13 / 26) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Forsmark

Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 320.000 - 340.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

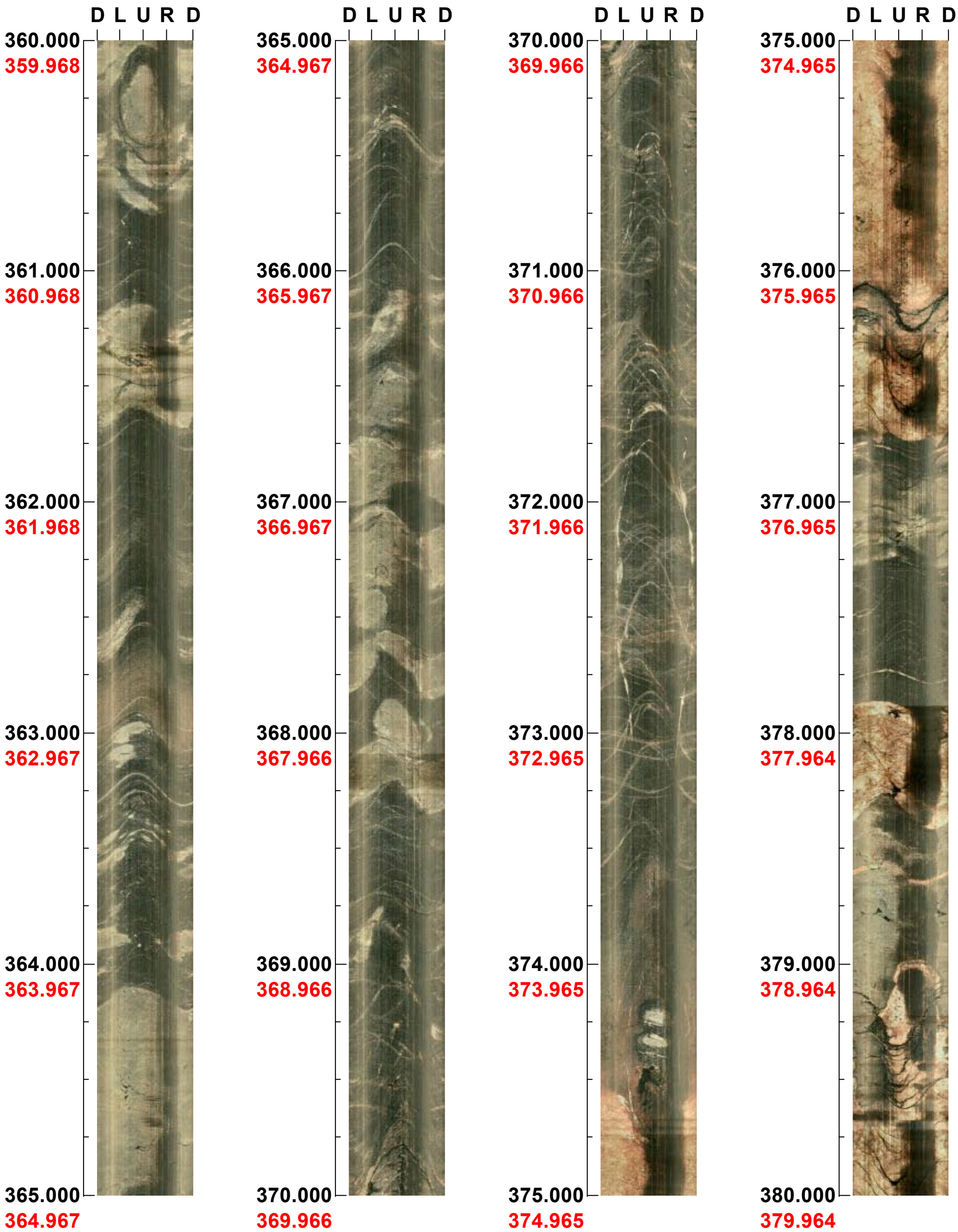
Depth range: 340.000 - 360.000 m

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

Project name: Forsmark

Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

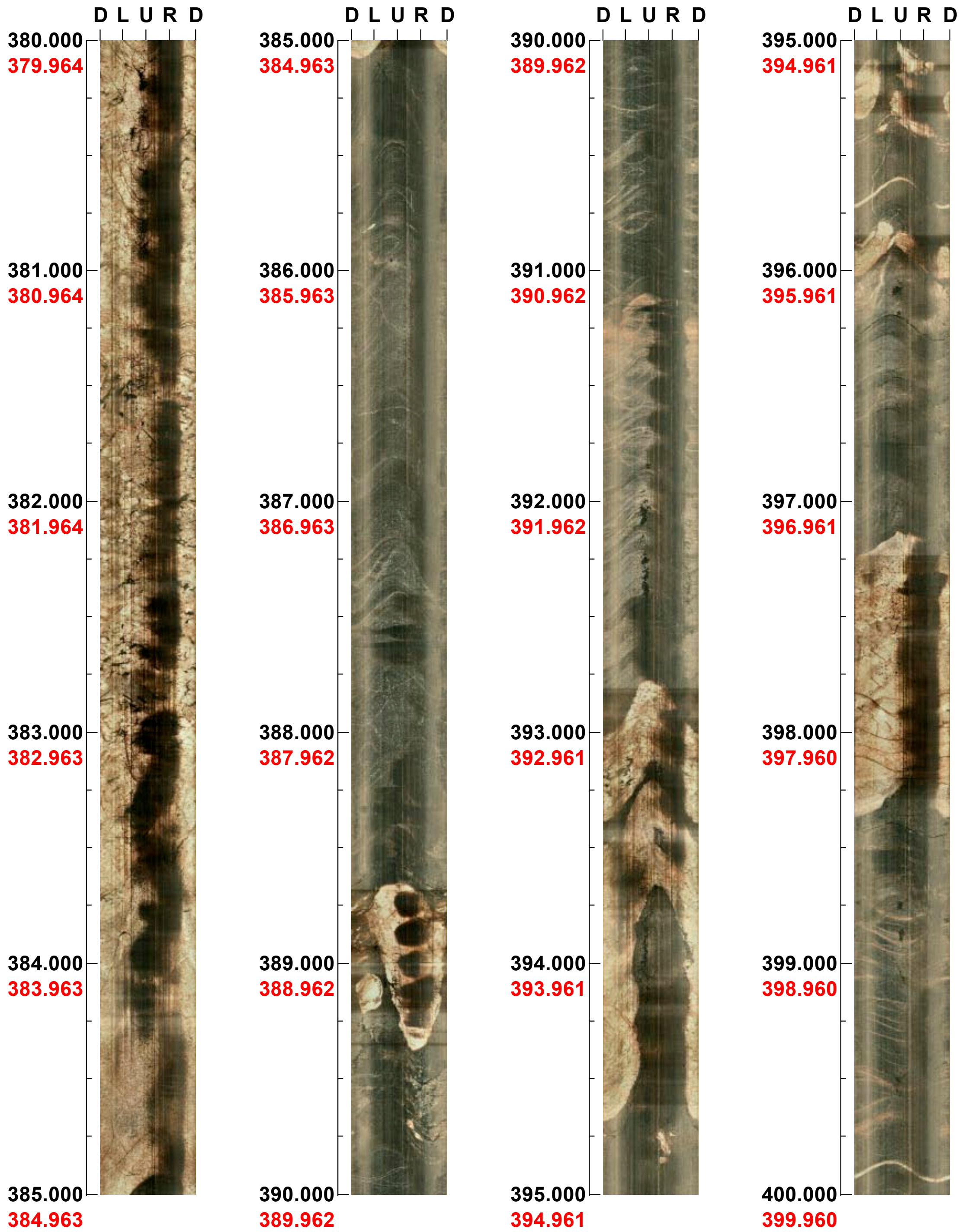
Depth range: 360.000 - 380.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 380.000 - 400.000 m



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

Project name: Forsmark

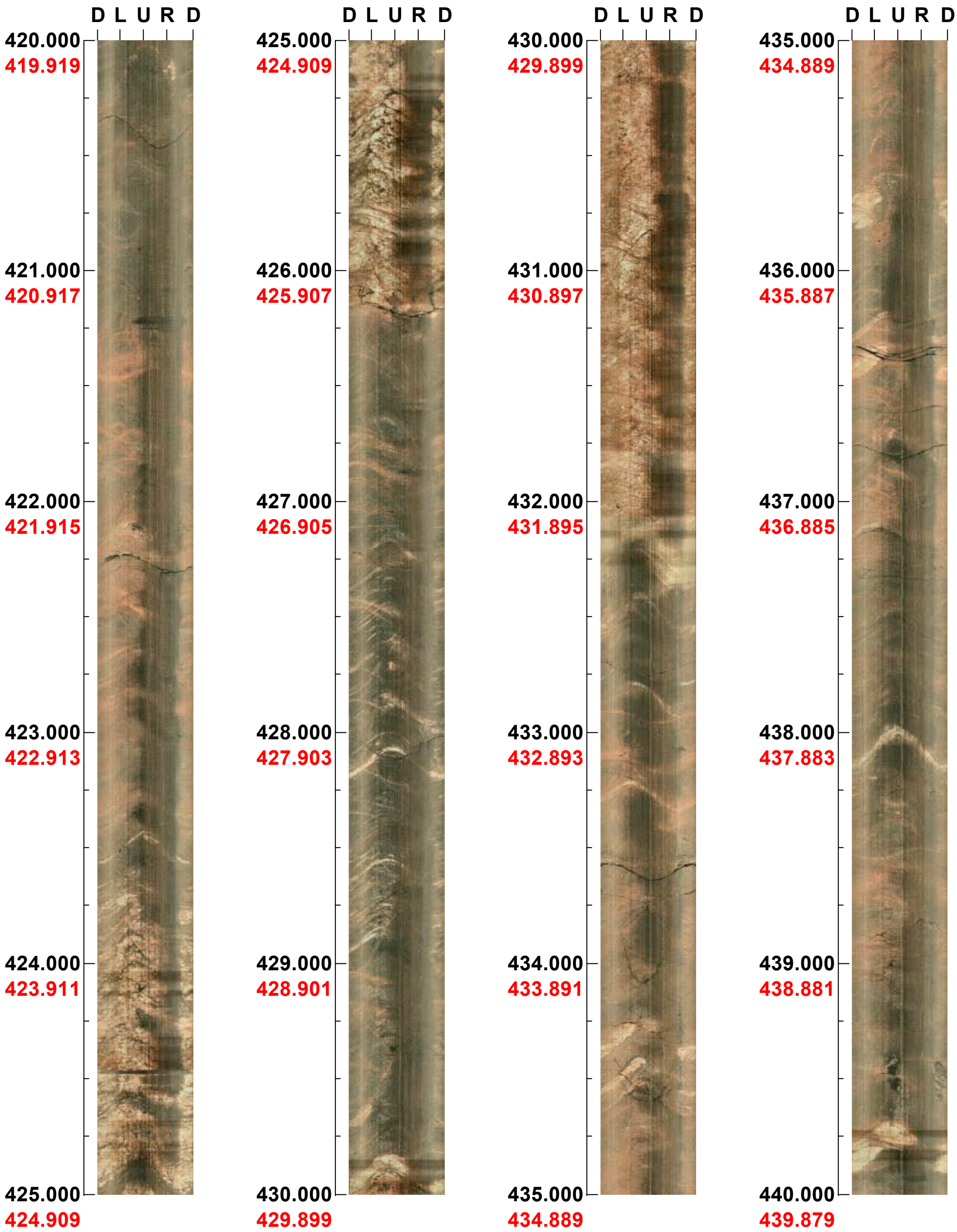
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 400.000 - 420.000 m

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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 420.000 - 440.000 m

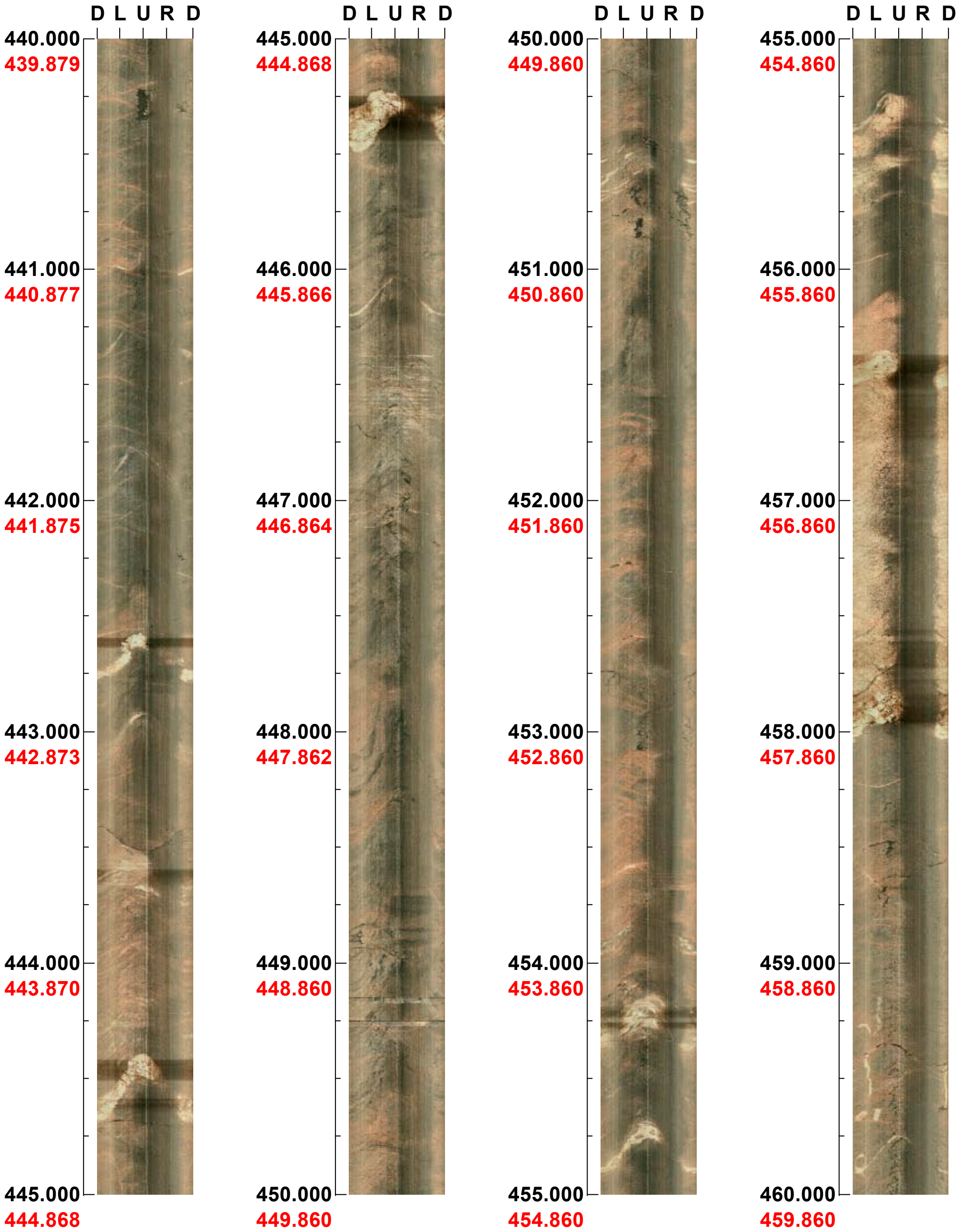


(19 / 26) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Forsmark

Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

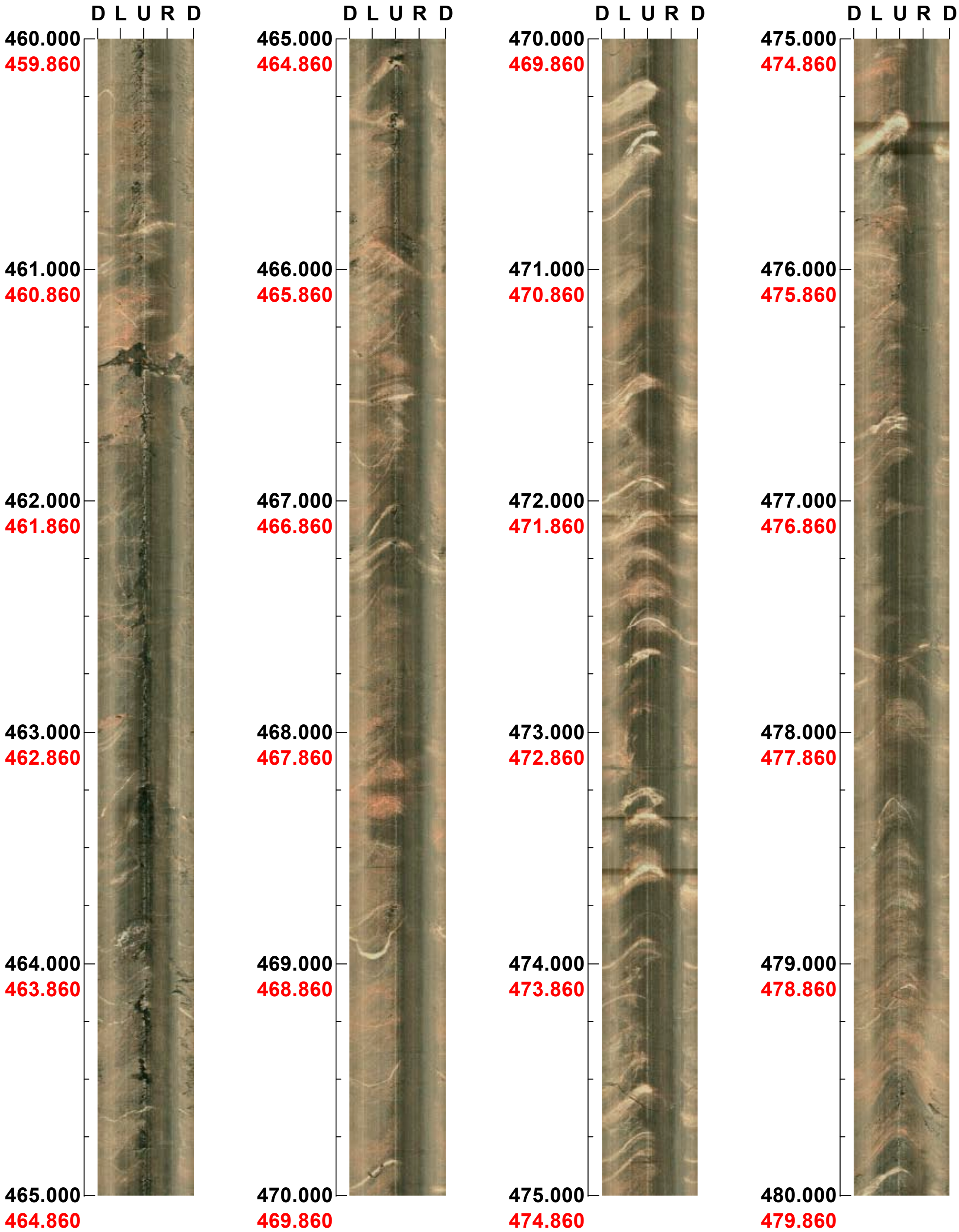
Depth range: 440.000 - 460.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 460.000 - 480.000 m

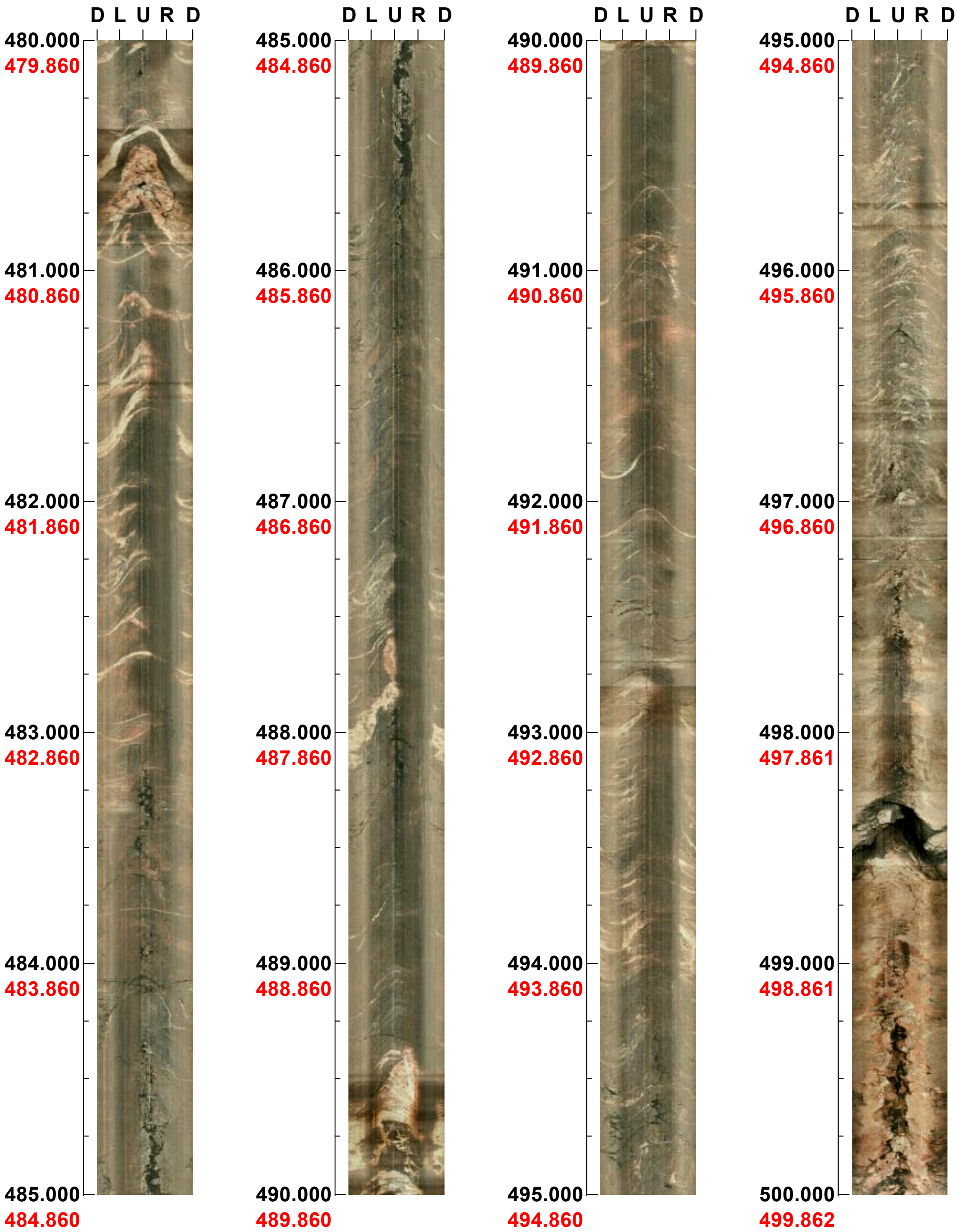


(21 / 26) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Forsmark

Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

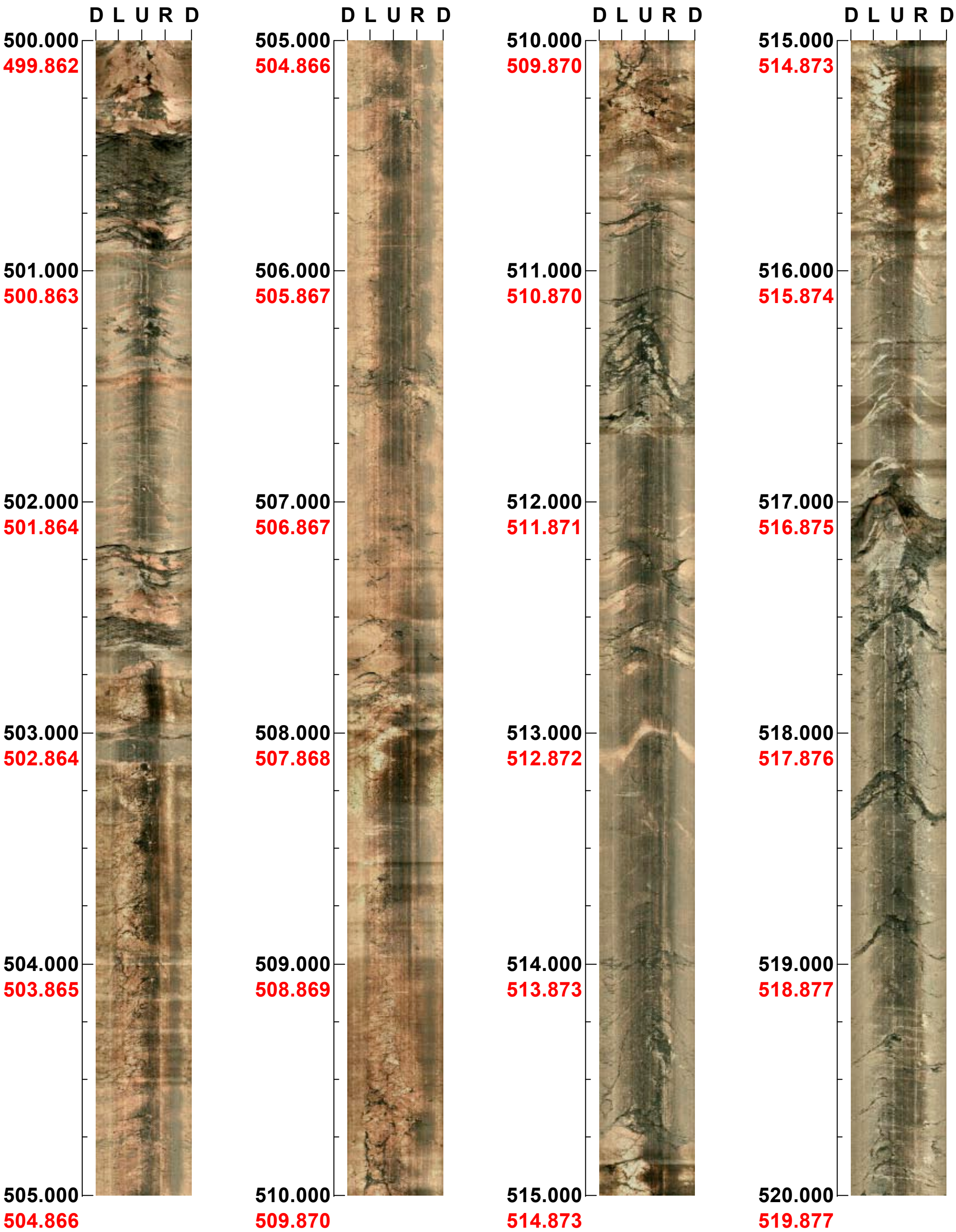
Depth range: 480.000 - 500.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A Azimuth: 40 Inclination: -61

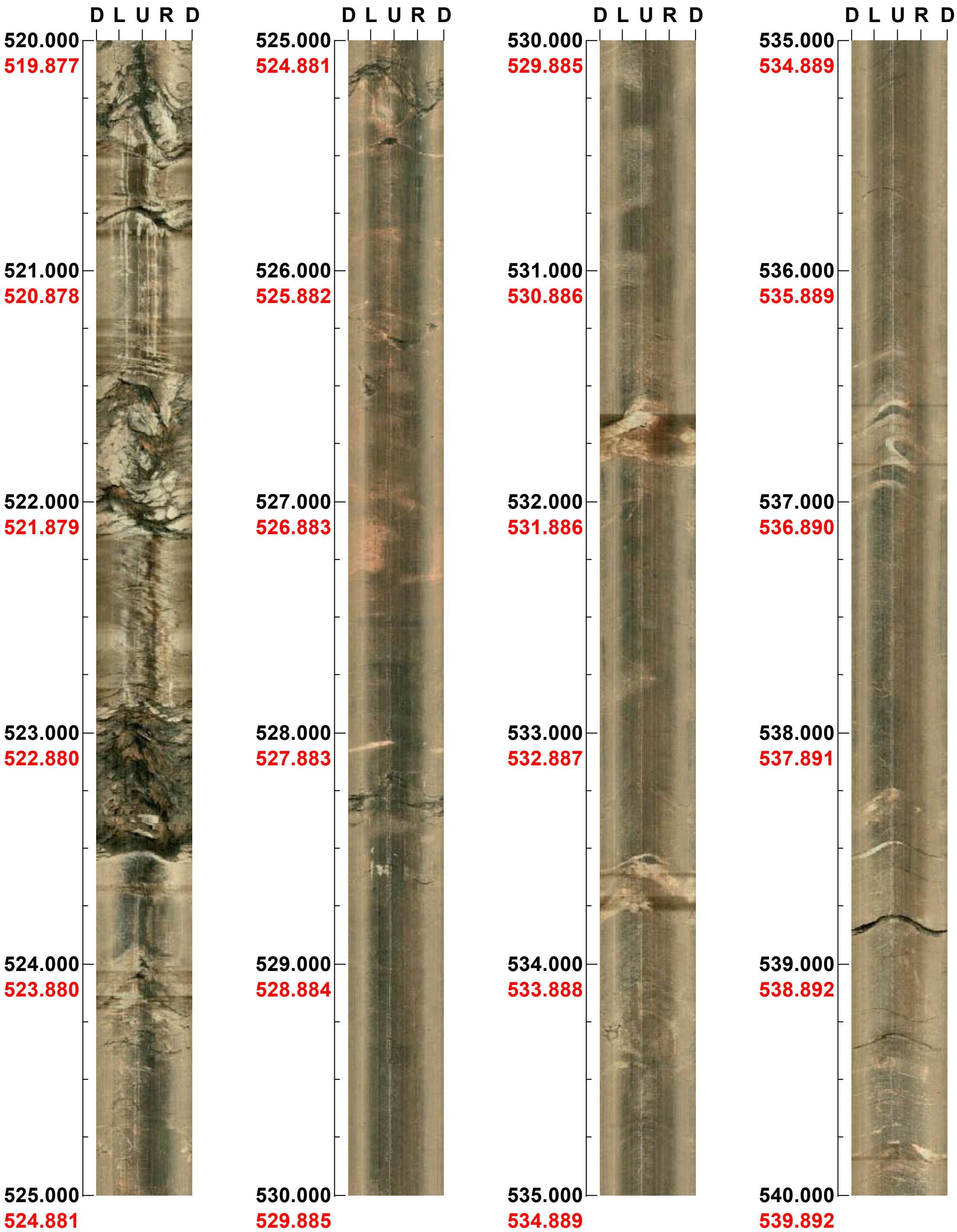
Depth range: 500.000 - 520.000 m



(23 / 26) Scale: 1/25 Aspect ratio: 175 %

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 520.000 - 540.000 m



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

Project name: Forsmark

Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 540.000 - 560.000 m

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

Project name: Forsmark

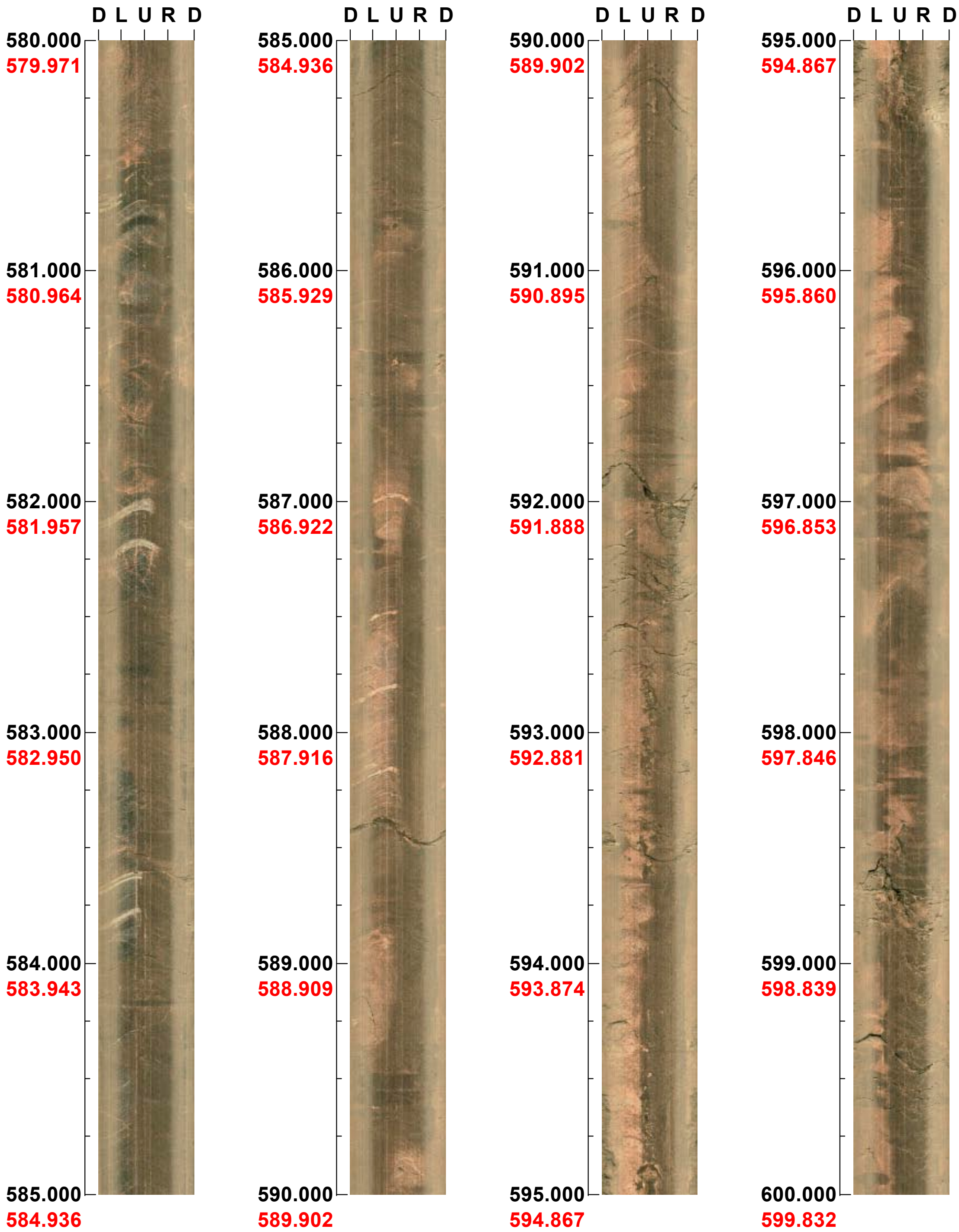
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 560.000 - 580.000 m

(1 / 15) Scale: 1/25 Aspect ratio: 175 %

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 580.000 - 600.000 m

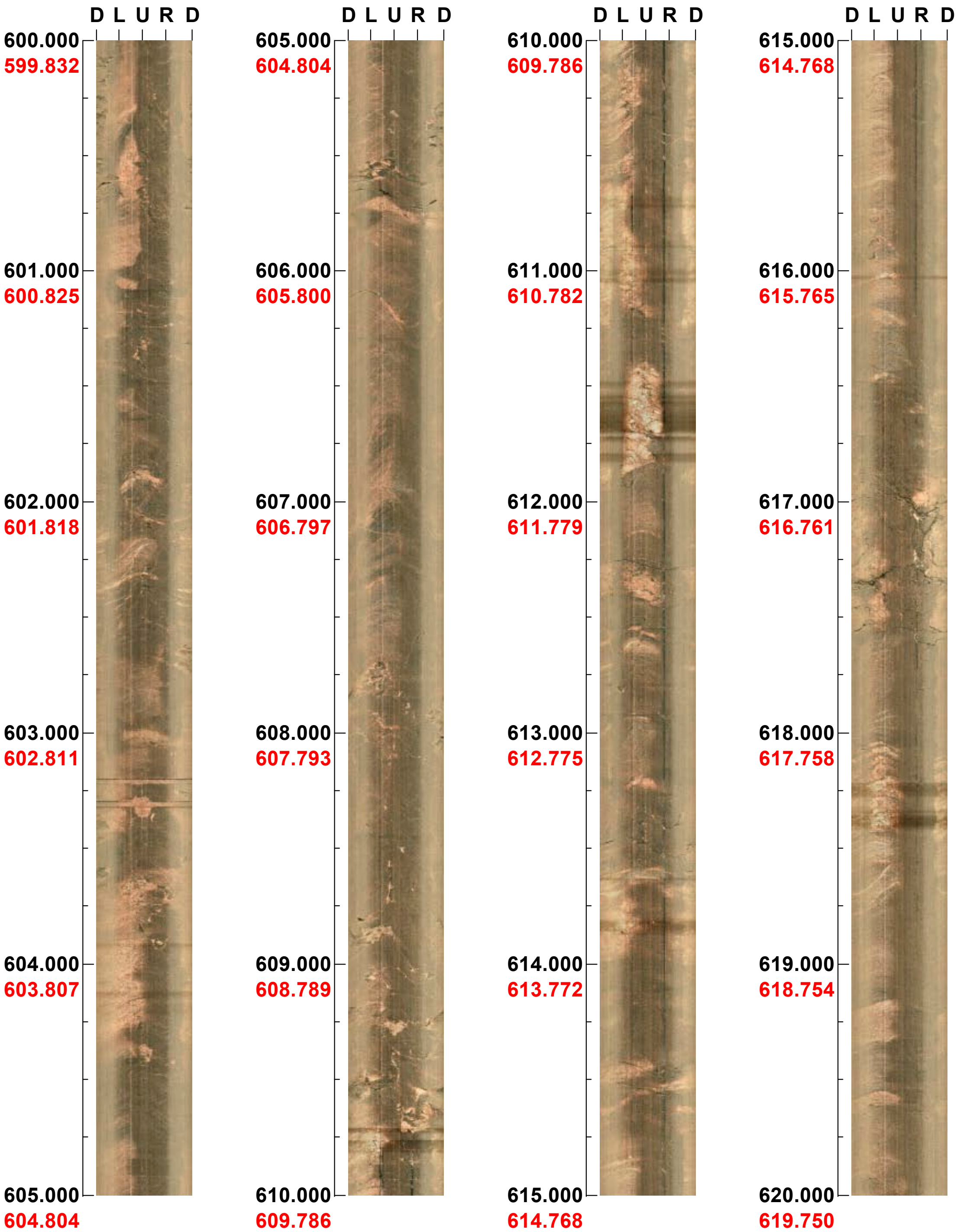


(2 / 15) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Forsmark

Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

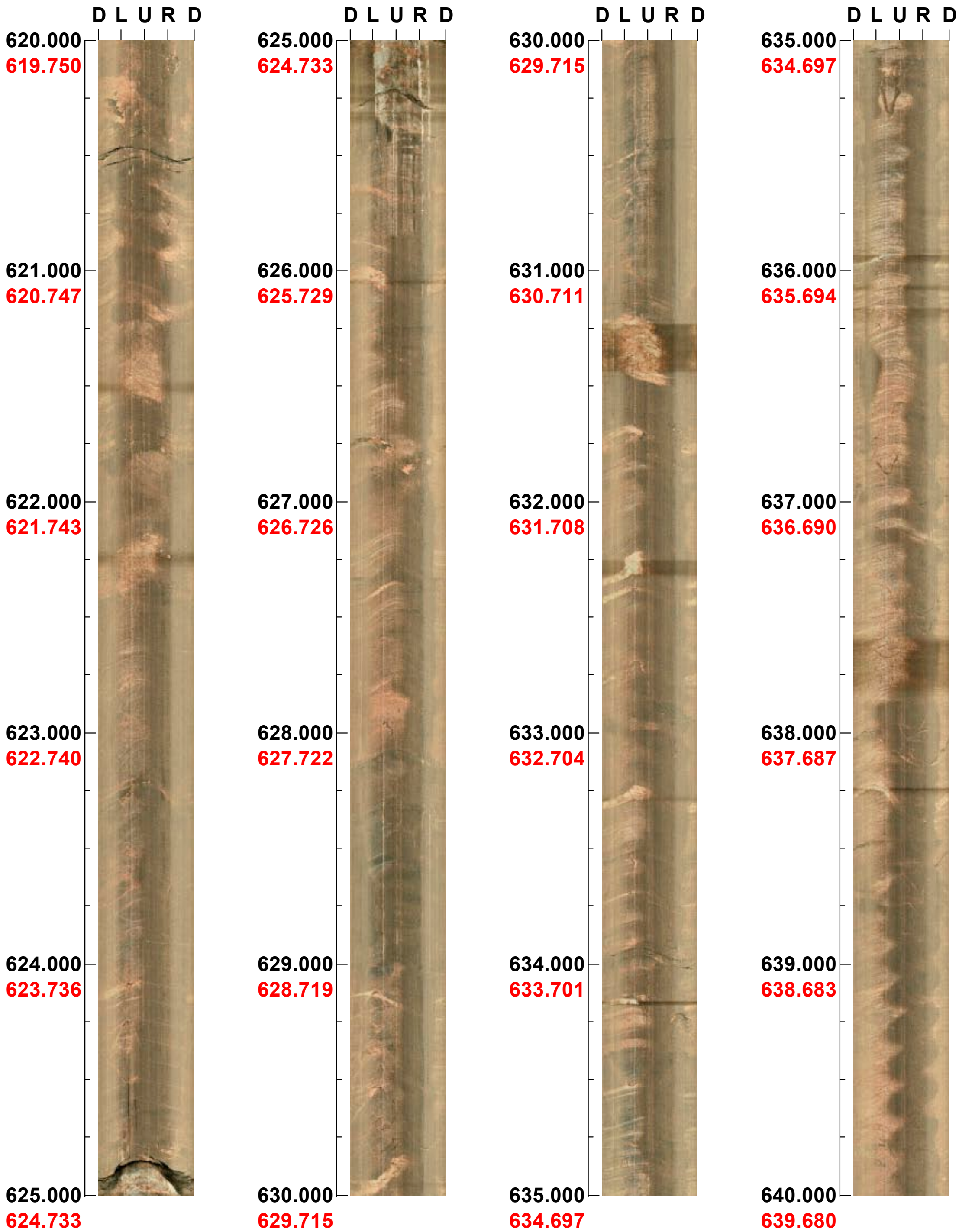
Depth range: 600.000 - 620.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

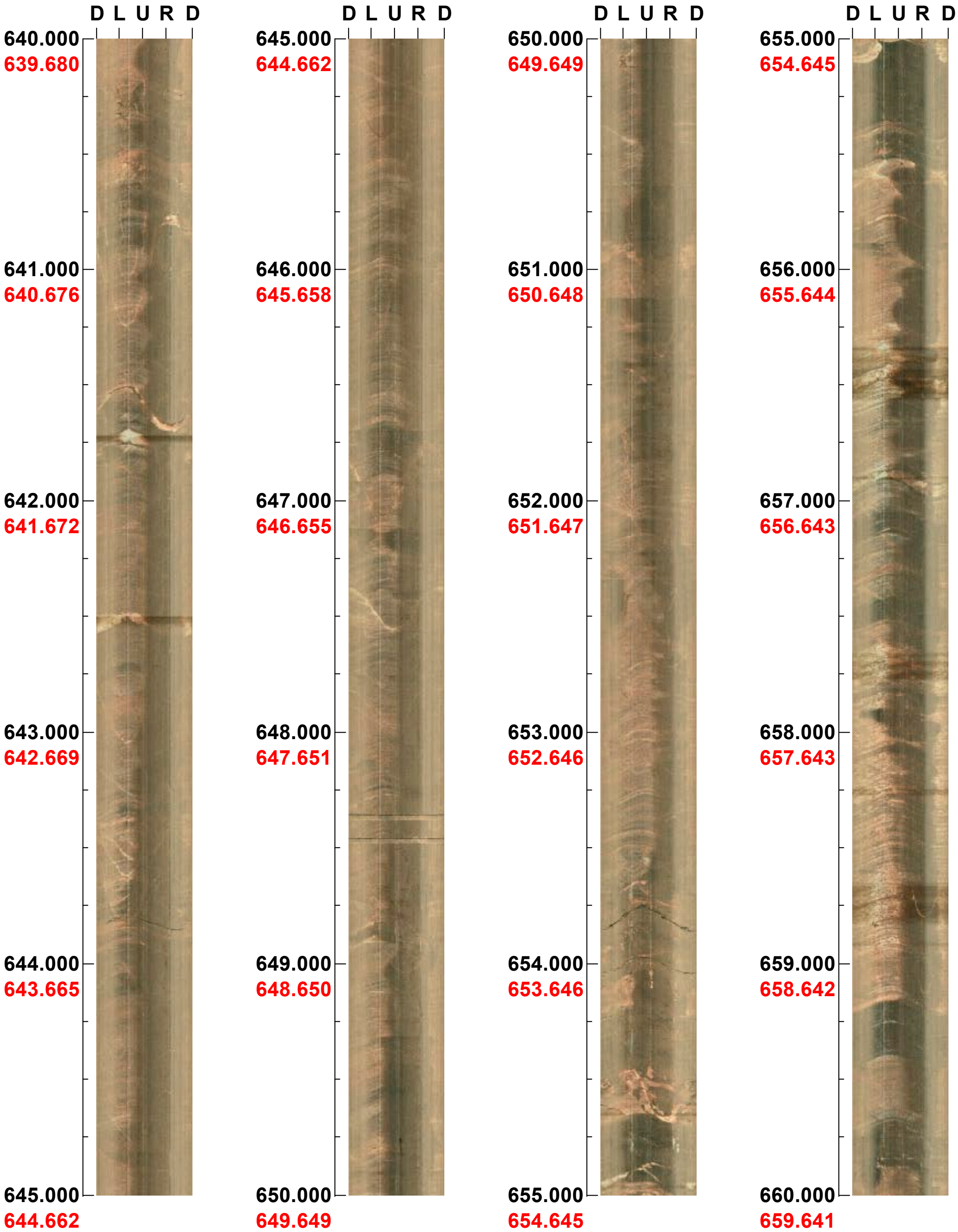
Depth range: 620.000 - 640.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

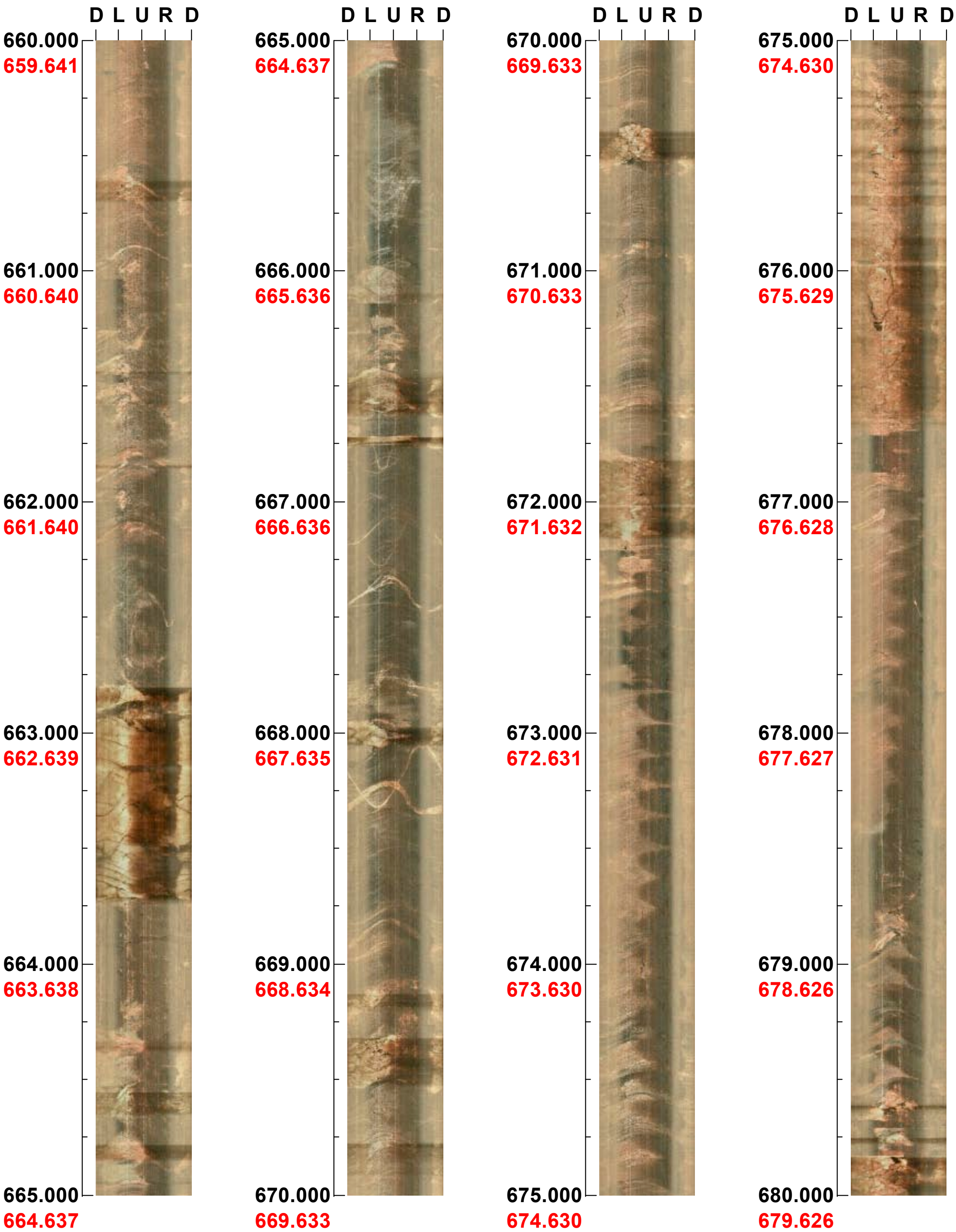
Depth range: 640.000 - 660.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 660.000 - 680.000 m

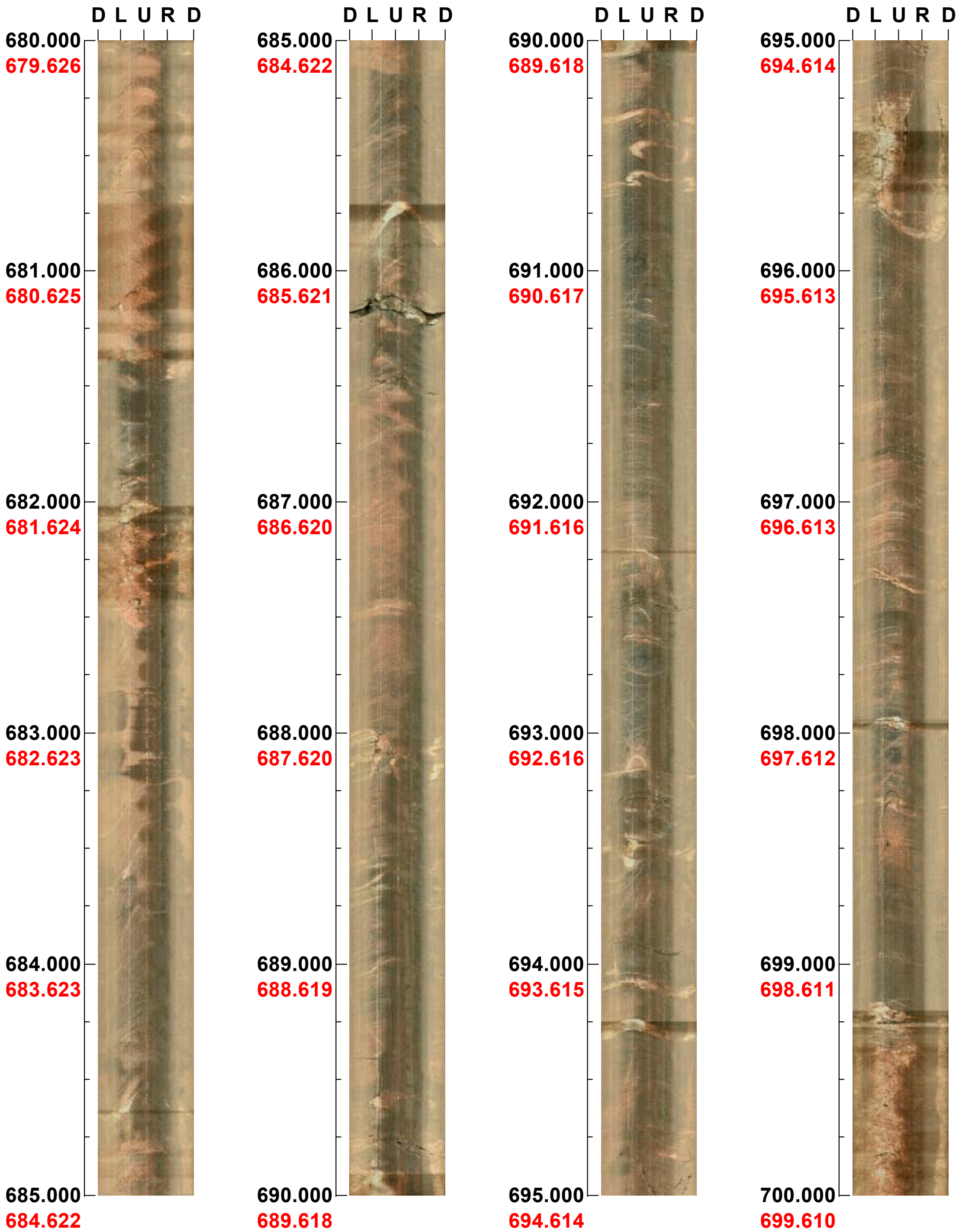


(6 / 15) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Forsmark

Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

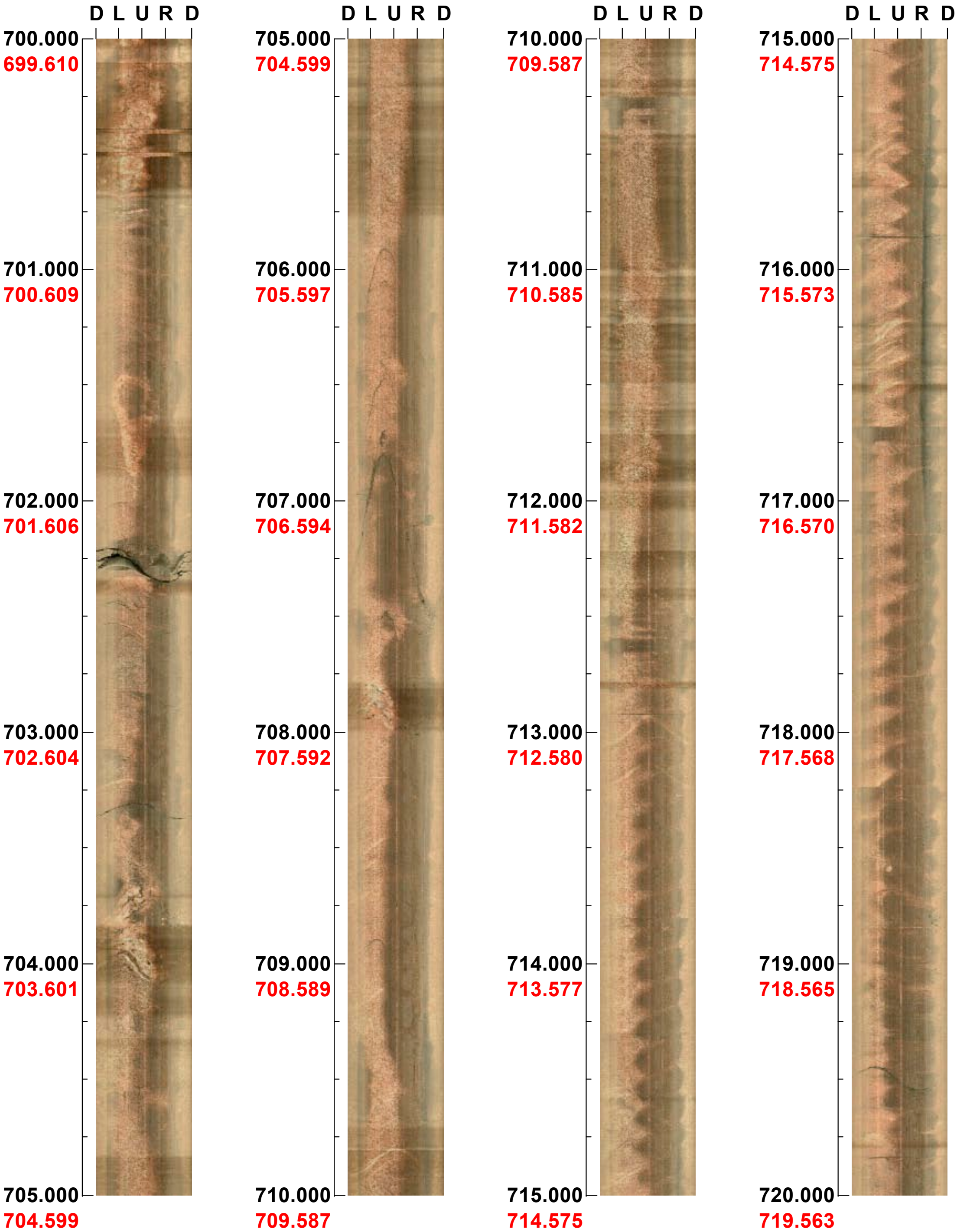
Depth range: 680.000 - 700.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

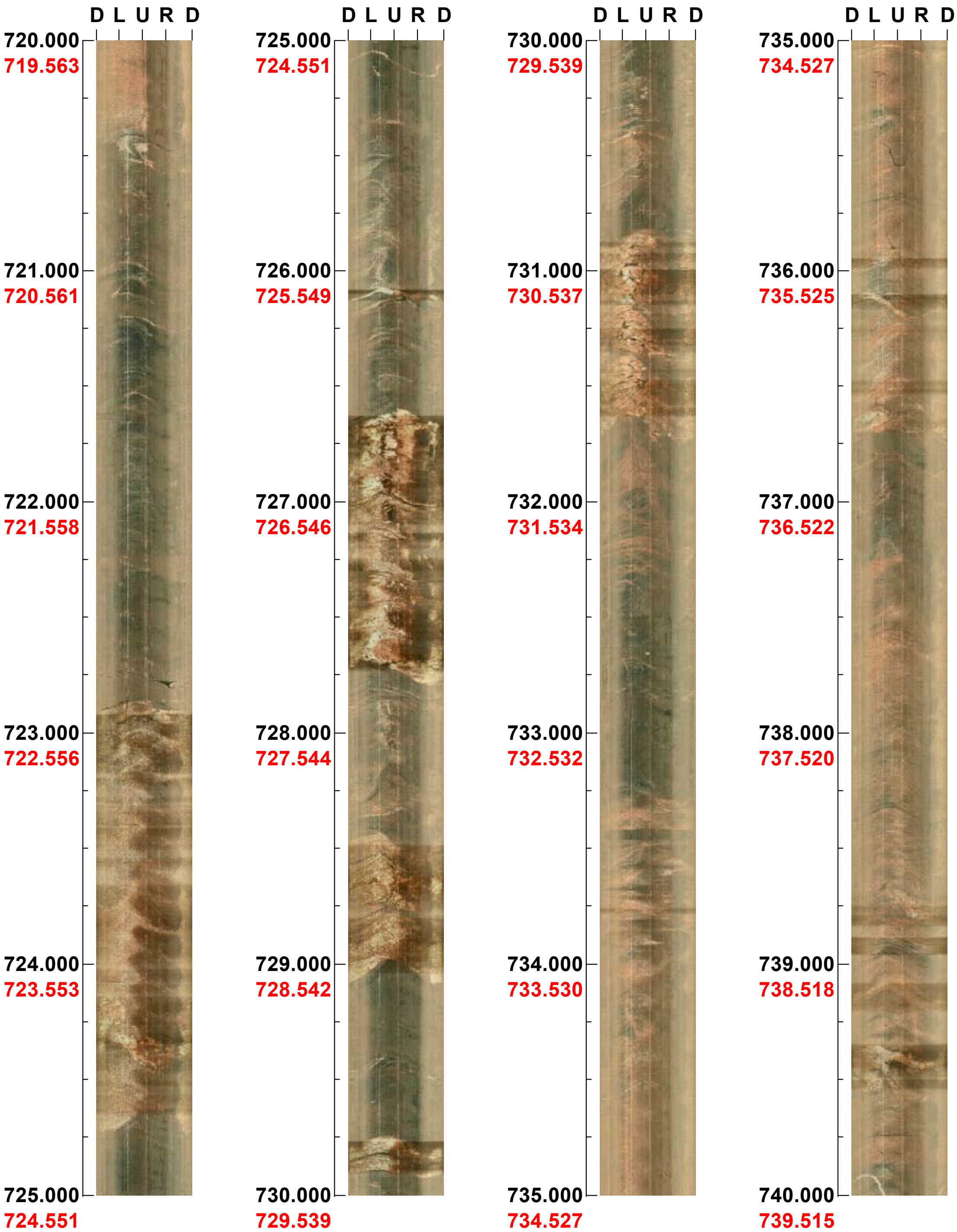
Depth range: 700.000 - 720.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

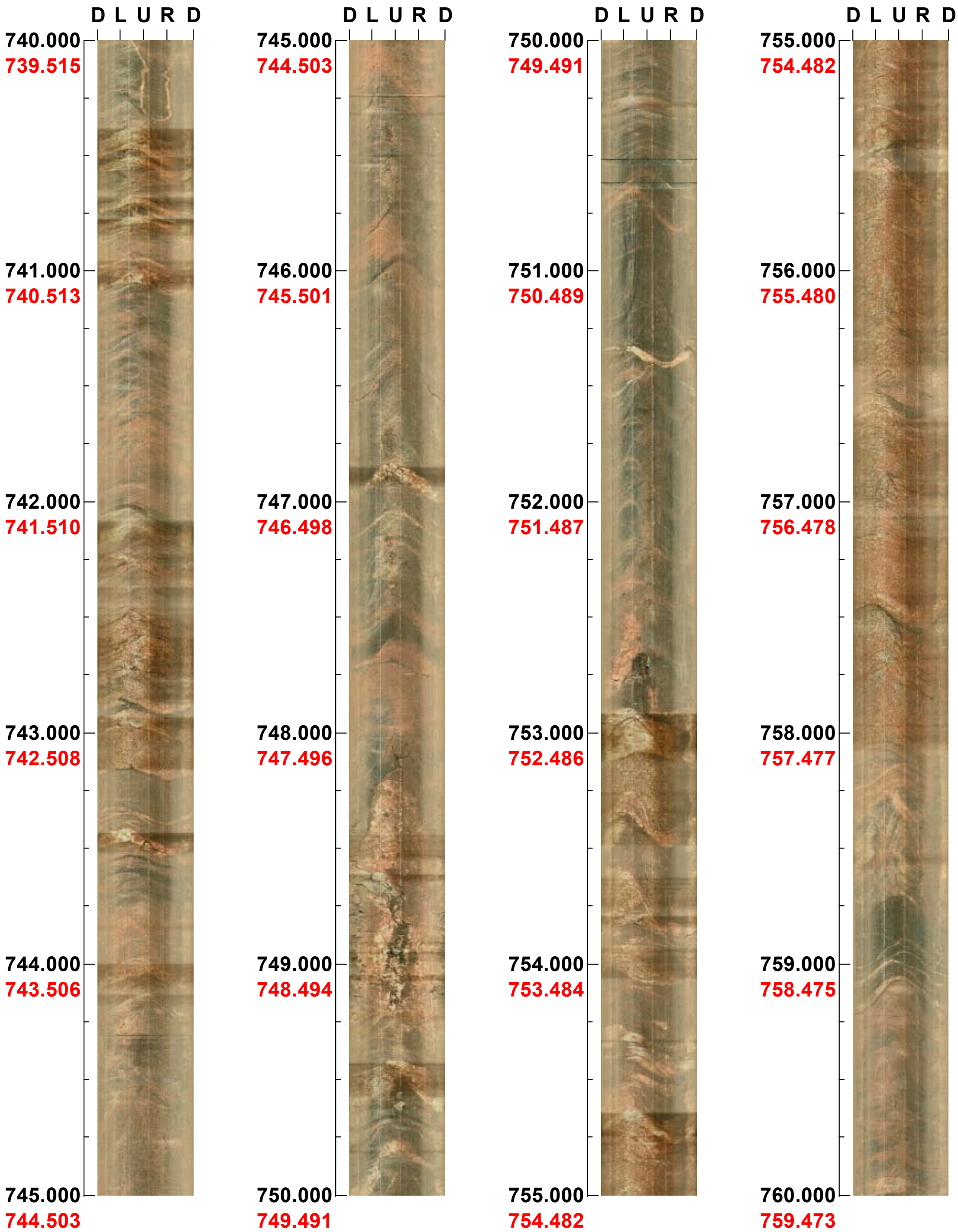
Depth range: 720.000 - 740.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 740.000 - 760.000 m

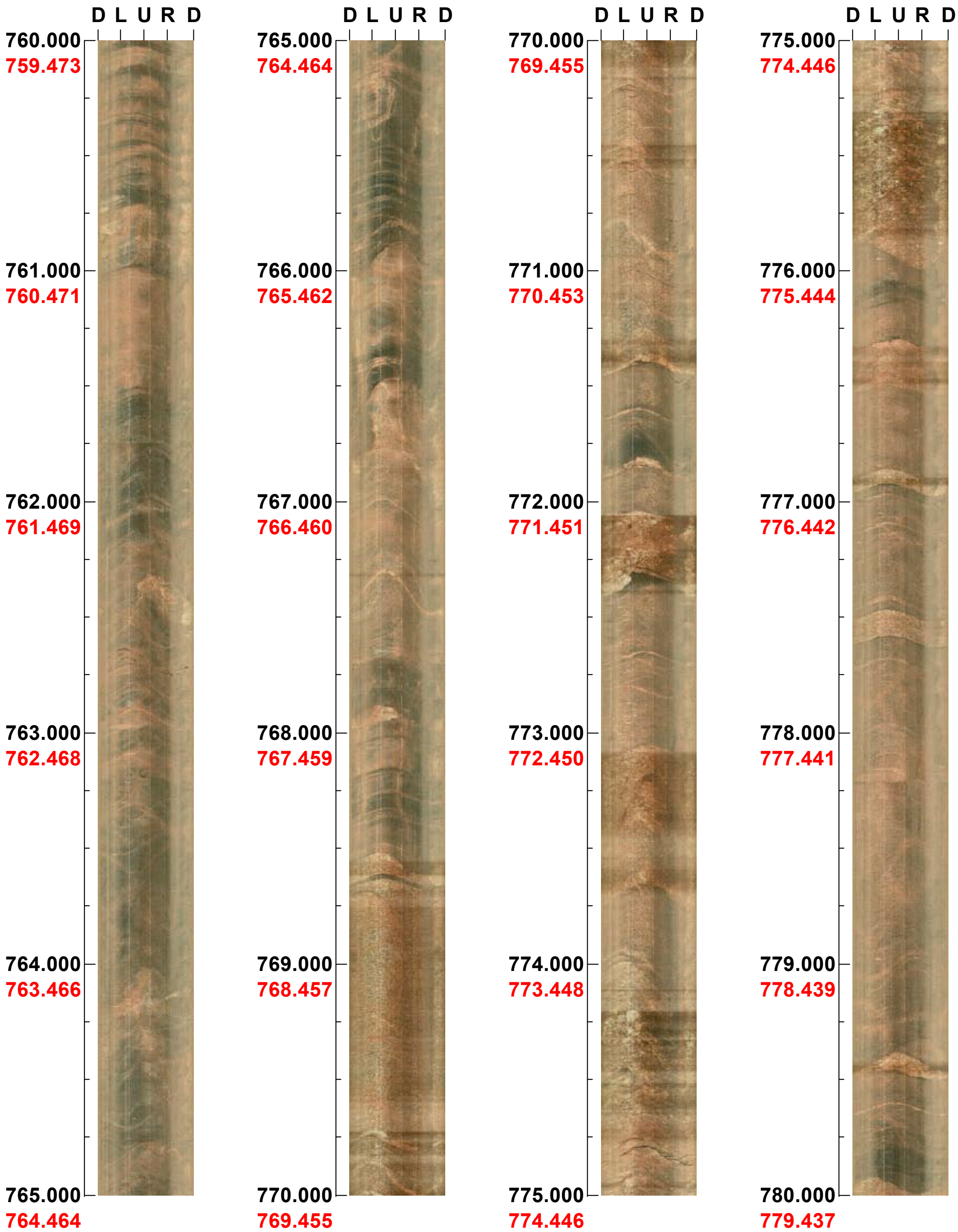


(10 / 15) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Forsmark

Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

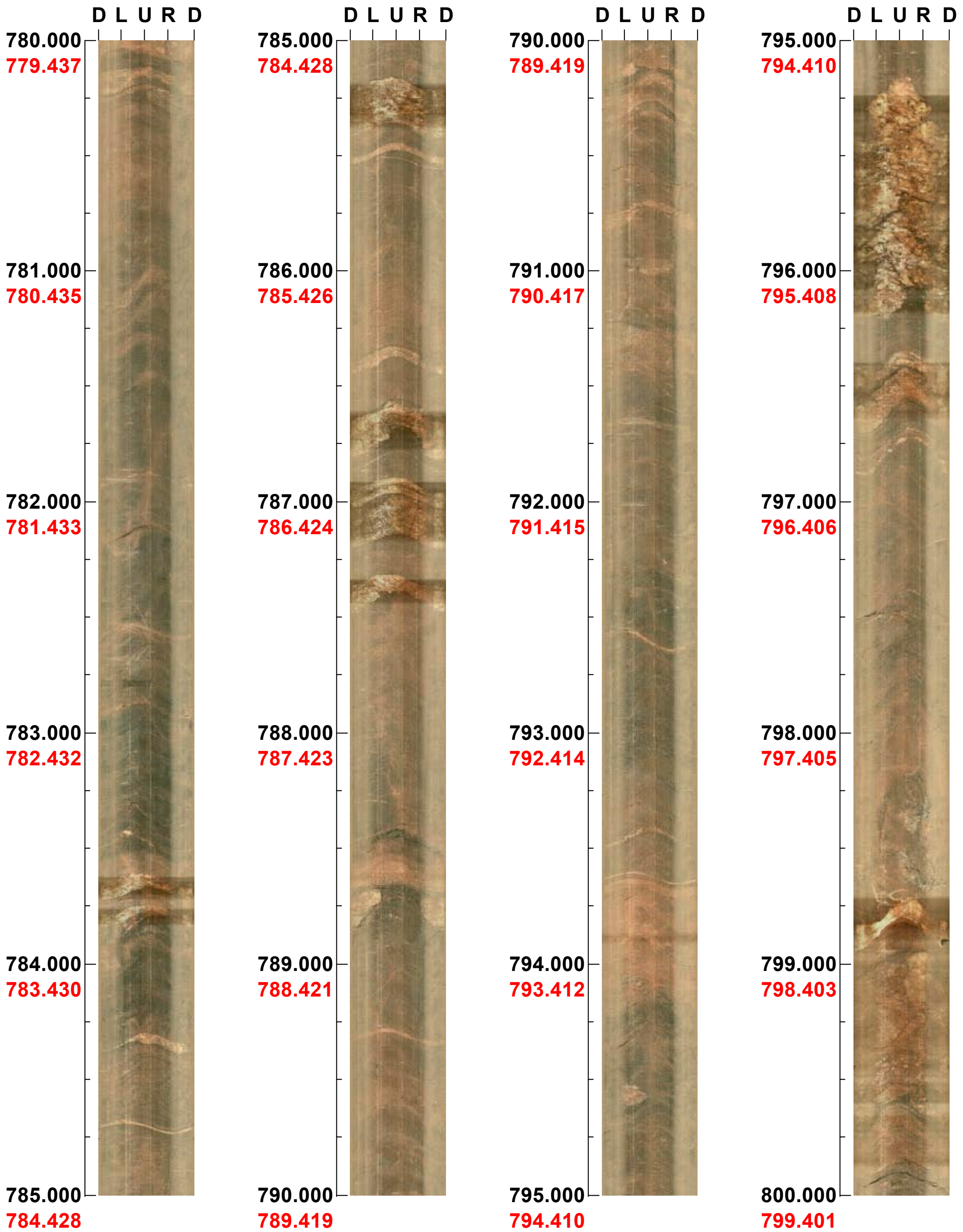
Depth range: 760.000 - 780.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

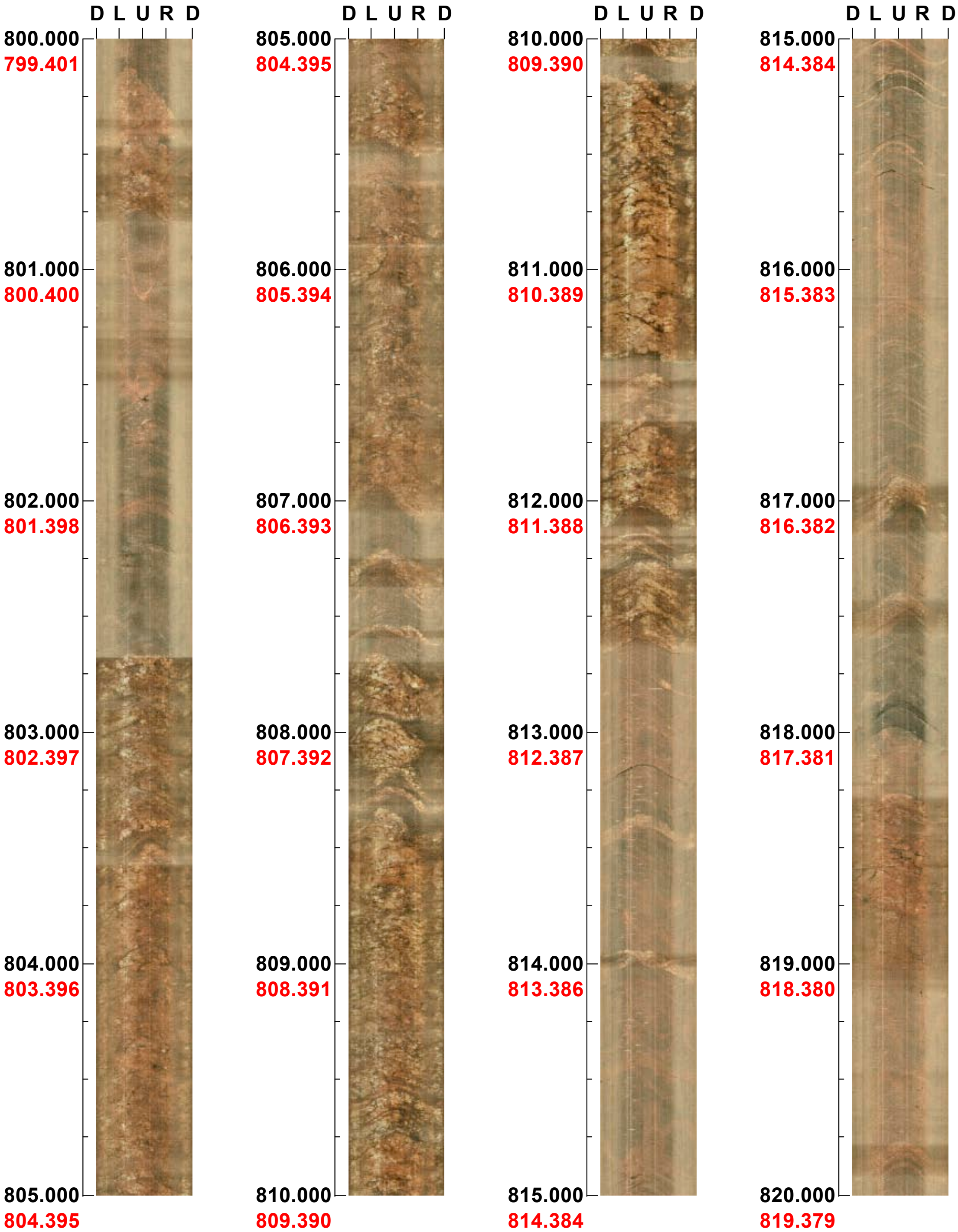
Depth range: 780.000 - 800.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

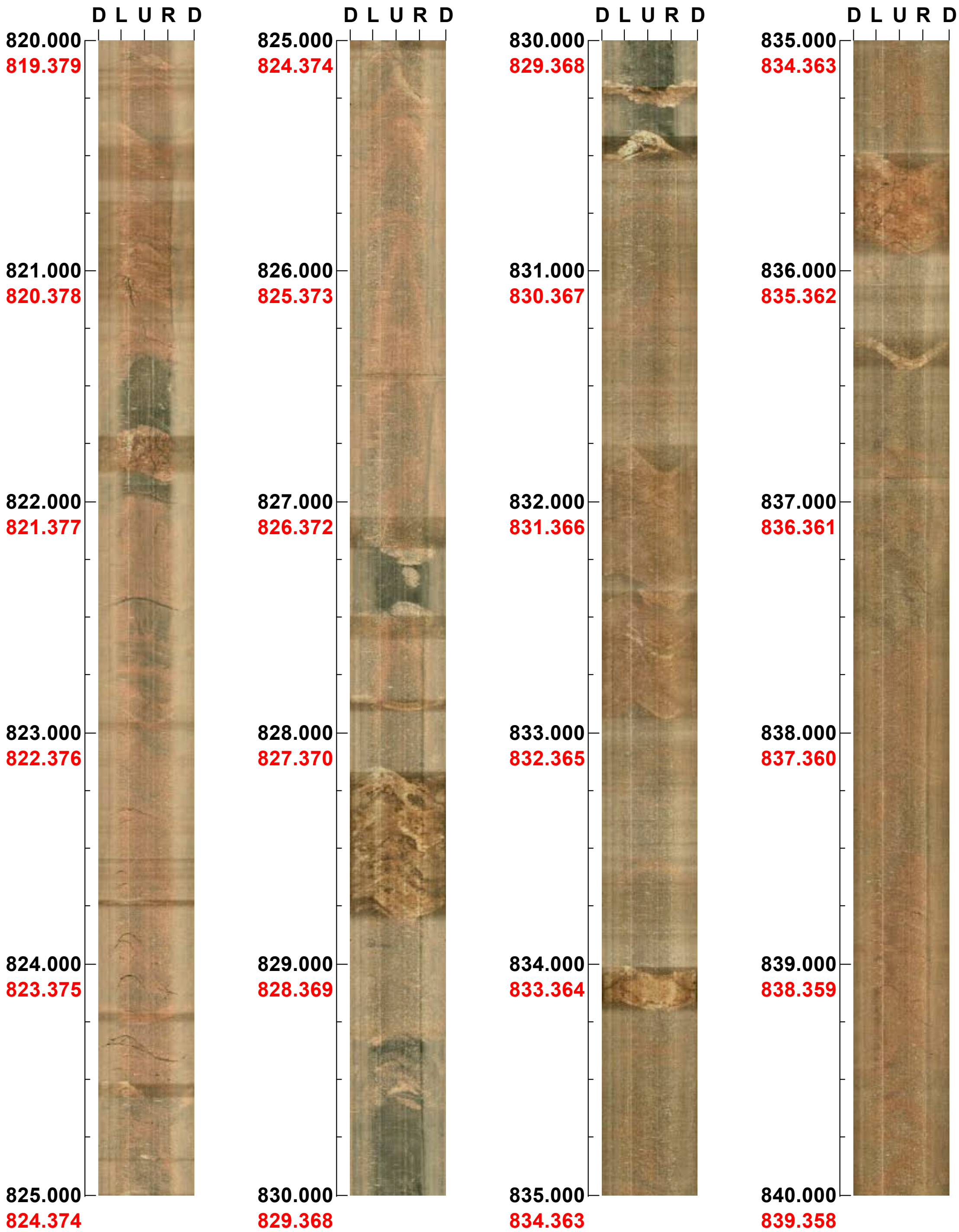
Depth range: 800.000 - 820.000 m



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

Project name: Forsmark
Bore hole No.: KFM11A Azimuth: 40 Inclination: -61

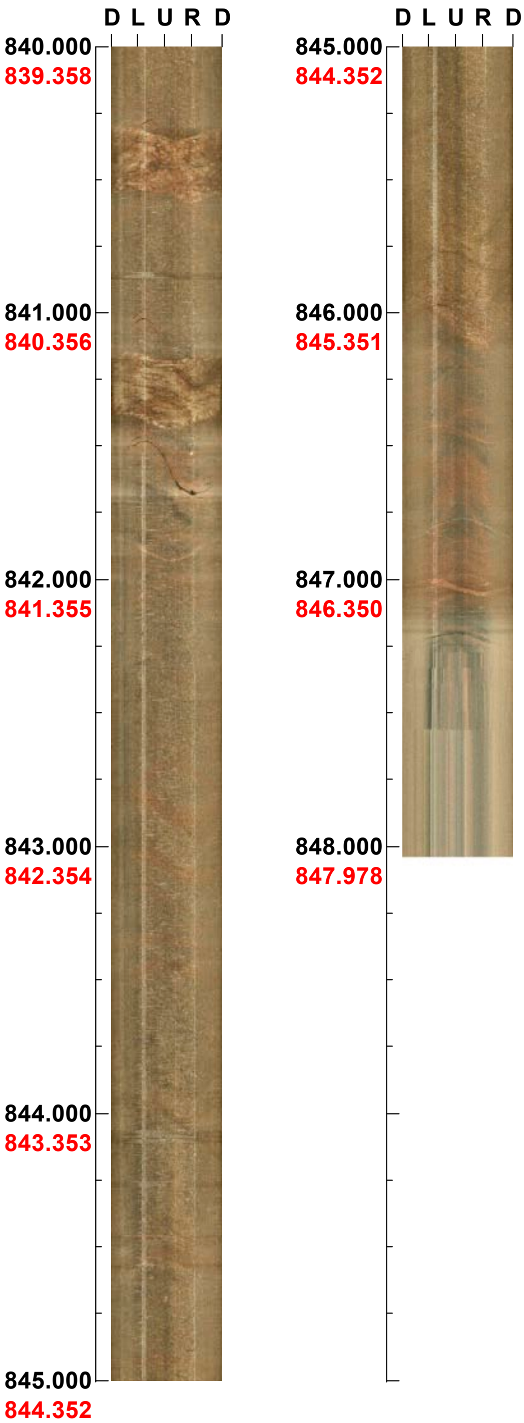
Depth range: 820.000 - 840.000 m



(14 / 15) Scale: 1/25 Aspect ratio: 175 %

Project name: Forsmark
Bore hole No.: KFM11A **Azimuth: 40** **Inclination: -61**

Depth range: 840.000 - 848.035 m



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