P-07-112

Forsmark site investigation

RAMAC and BIPS logging in borehole KFM12A

Jaana Gustafsson, Christer Gustafsson
Malå GeoScience AB/RAYCON

May 2007

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

ISSN 1651-4416
SKB P-07-112

Forsmark site investigation

RAMAC and BIPS logging in borehole KFM12A

Jaana Gustafsson, Christer Gustafsson
Malå GeoScience AB/RAYCON

May 2007

Keywords: BIPS, RAMAC, Radar, TV, Forsmark, AP PF 400-07-025.

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

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

A pdf version of this document can be downloaded from www.skb.se.

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 KFM12A. All measurements were conducted by Malå Geoscience AB during March 2007.

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 borehole.

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 KFM12A 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 180 identified radar reflectors of which 21 were orientated (dip/strike).

Despite the presence of mud covering the lowermost part of the borehole wall, the BIPS images are relatively good, thanks to perfect water quality and lack of discolouring of the borehole walls.

Sammanfattning

Denna rapport omfattar geofysiska loggningar inom platsundersökningsprogrammet för Forsmark. Mätningarna som presenteras här omfattar BIPS-loggning och borrhålsradarmätningar (RAMAC) i kärnborrhålet KFM12A. Alla mätningar är utförda av Malå Geoscience AB under mars 2007.

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 KFM12A 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 180 radarreflektorer identifierats i KFM12A, varav 21 är orienterade (strykning och stupning).

Trots att borrkax täcker den nedre delen av borrhålsväggen längs hela borrhålet är BIPS bilderna relativt bra, tack vare mycket bra vattenkvalitet och avsaknad av de vanliga svärtningarna från borrningen.

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 KFM12A. The work was carried out in accordance with activity plan AP PF 400-07-025. 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 61 m to approximately 598 m in borehole KFM12A. The borehole diameter is 77.3 mm.

All measurements were conducted by Malå Geoscience AB during March 2007. 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.

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the Activity Plan number (AP PF 400-07-025). Only data in SKB's databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

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

Activity plan	Number	Version
BIPS och RADAR-l loggning i KFM12A	AP PF 400-07-025	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

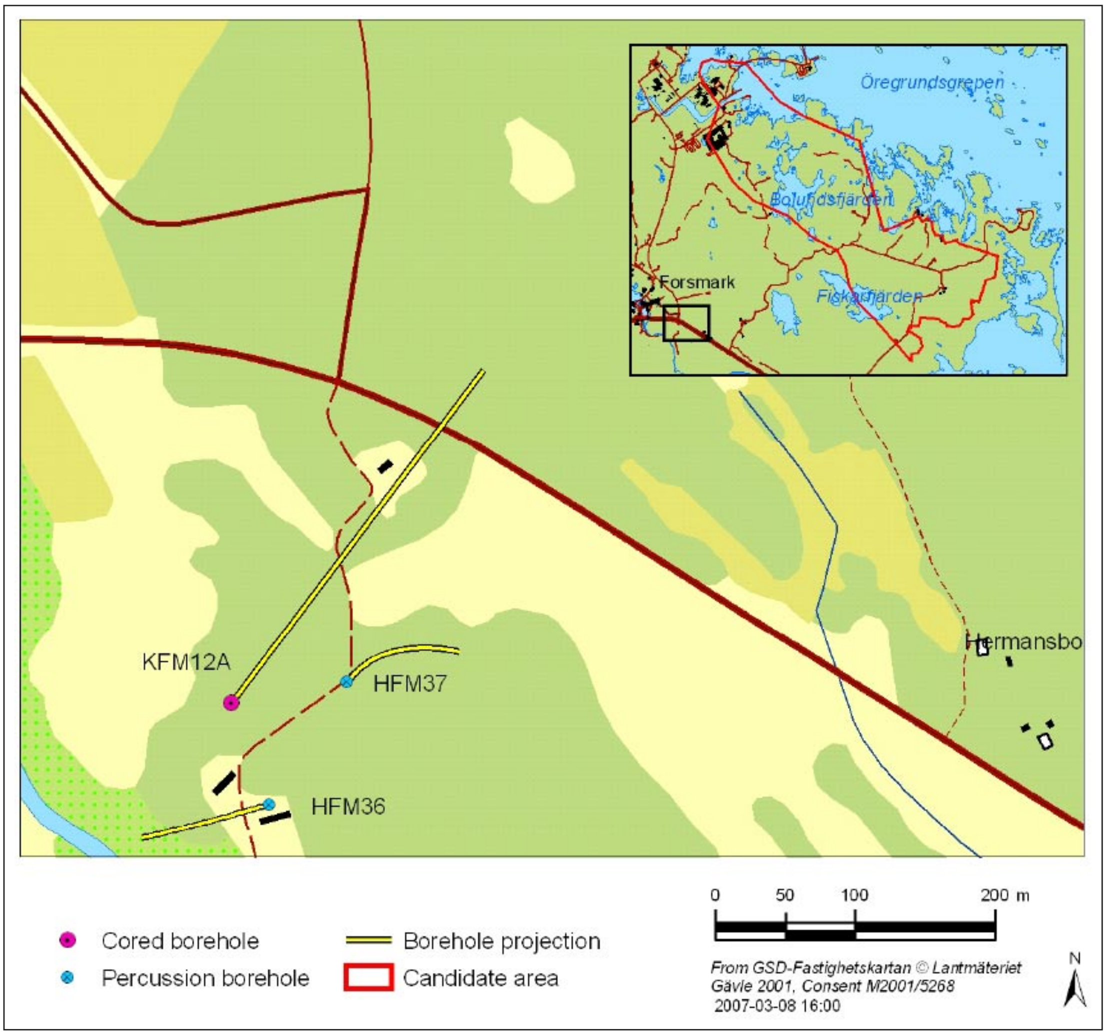


Figure 1-1. *Overview over the Forsmark investigation area and Drill Site 12, showing the location of the borehole KFM12A surveyed and presented in this report.*

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 borehole, 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 252.020.

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.

3.2 TV-Camera, BIPS

The BIPS 1500 system used is owned by SKB and described in SKB internal controlling document MD 222.006. 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).

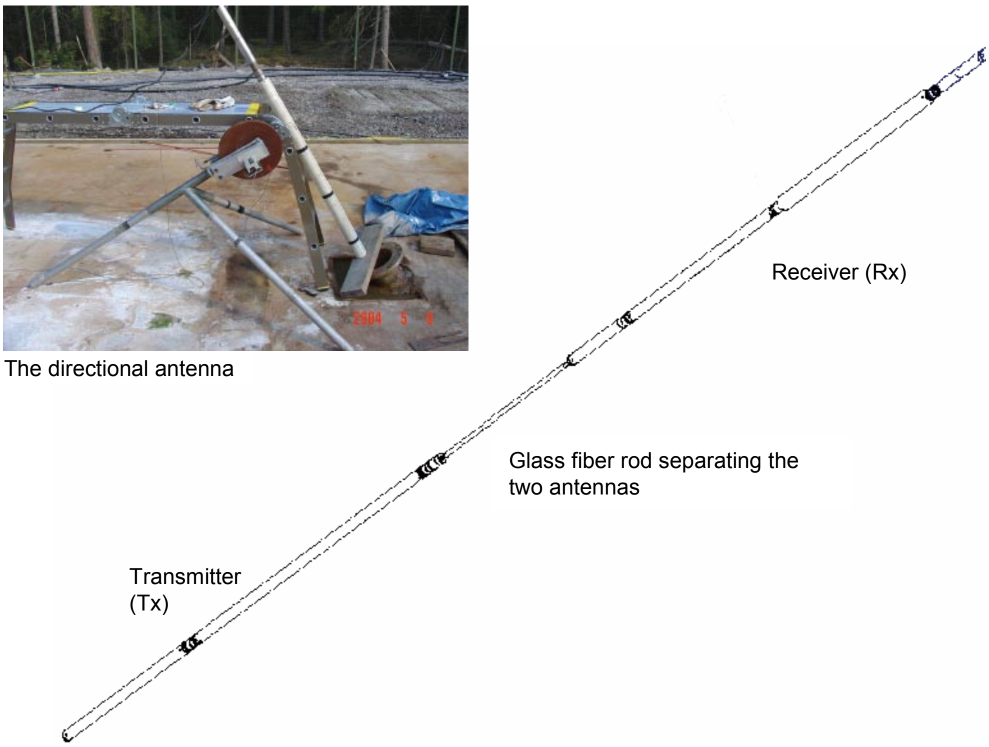


Figure 3-1. *Example of a borehole radar antenna.*

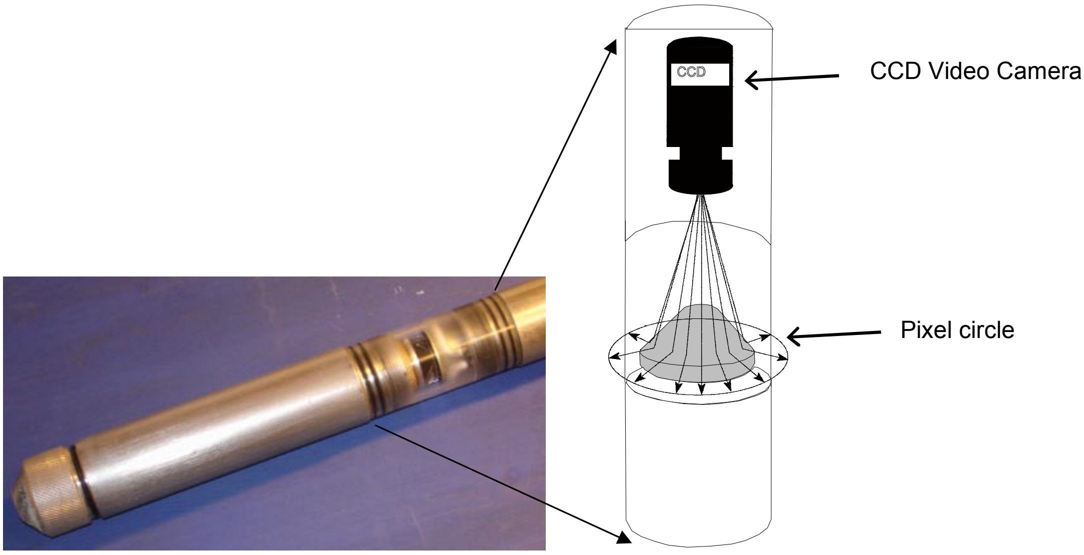


Figure 3-2. *The BIPS-system. To the right a sketch showing the principles of the conical mirror.*

4 Execution

4.1 General

4.1.1 RAMAC Radar

The measurements in KFM12A 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.

Table 4-1. Radar logging information from KFM12A.

Site:	**Forsmark**	**Logging company:**	**Malå Geoscience AB**		
BH:	**KFM12A**	**Equipment:**	**SKB RAMAC**		
Type:	**Directional / Dipole**	**Manufacturer:**	**MALÅ Geoscience AB**		
Operator:	**CG**	**Antenna**			
		Directional	**250 MHz**	**100 MHz**	**20 MHz**
Logging date:		2007-03-22	2007-03-22	2007-03-22	2007-03-22
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):		63.4	61.5	62.6	66.35
Logging to (m):		583.4	597.3	596.8	592.25
Trace interval (m):		0.5	0.1	0.2	0.25
Antenna separation (m):		5.73	2.4	3.9	10.05

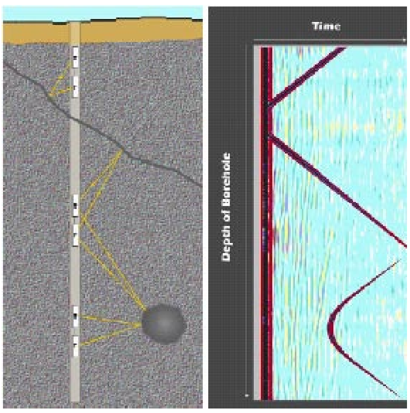


Figure 4-1. The principle of radar borehole reflection survey (left) and an example of result (right).

The functionality of the directional antenna was tested before measurements. 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 rotated 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 1 degree. This can be considered to be very good, considering the very disturbed environment with metallic objects etc at the test site.

For more information on system settings used in the investigation of KFM12A, see Table 4-1 below.

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 the borehole.

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 4-2. 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.

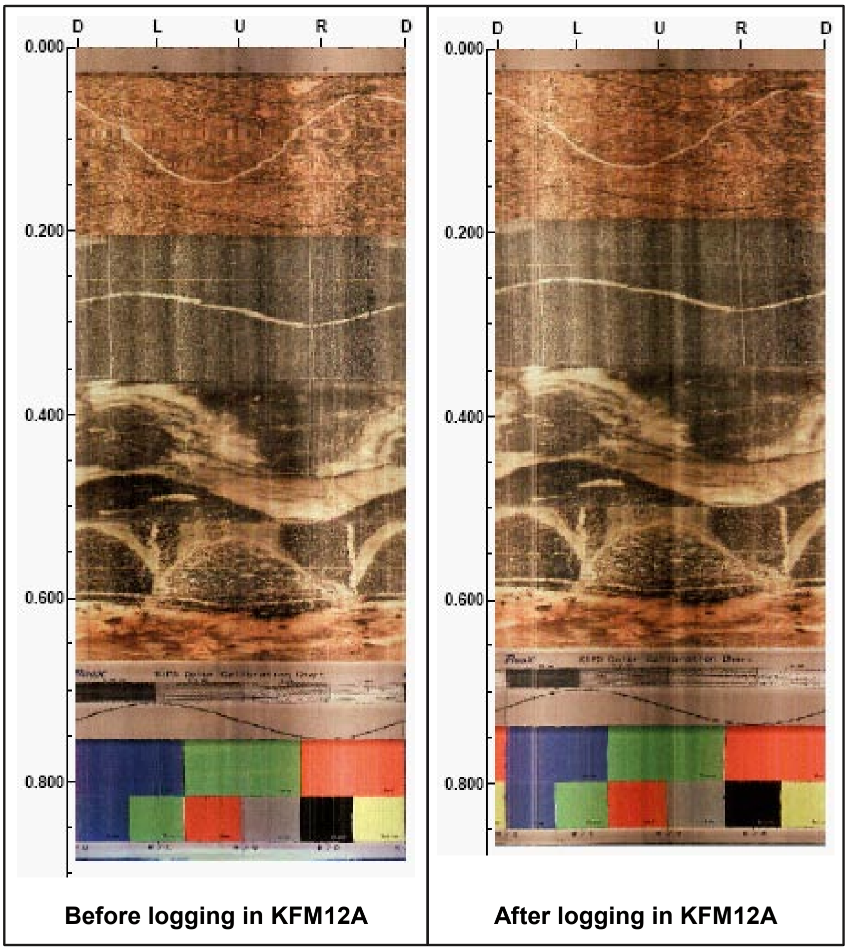


Figure 4-2. *Results from logging in the test pipe before and after the logging campaign in March, 21st to 23rd, 2007. The length scales are not essential in the test measurements.*

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 meter long borehole. The length divergence is taken into account in the resulting tables presented 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 4-3, and the calculation shows a velocity of 128 m/µs (metres per microsecond) /1/. The velocity measurement was performed with the 100 MHz antenna.

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.

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.

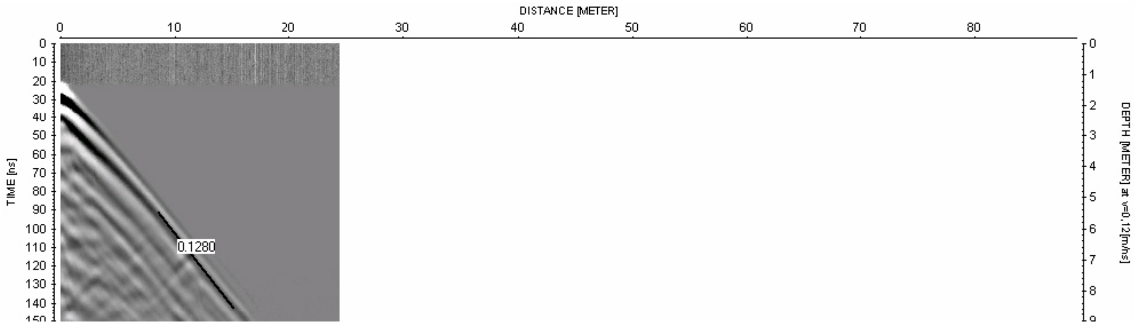


Figure 4-3. *Results from velocity measurements in HFM03.*

Table 4-2. Processing steps for borehole radar data from KFM12A.

Site: Forsmark	**Logging company:**	**MALÅ GeoScience AB**		
BH: KFM12A	**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 (41 samples)	Move start time (–11.6)	Move start time (–43.8)	Move start time (–81.6)
	DC shift (400–511)	DC shift (190–230)	DC shift (470–530)	DC shift (1,800–2,000)
	Time gain (start 89 lin 100 exp 1)	Gain (Start 9 lin 2.4 exp 0.3)	Gain (Start 23 lin 0.7 exp 0.4)	Gain (Start 52 lin 5 exp 0.07)
	(FIR)			Bandpass (10–100)

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 KFM12A in March 2007.

5 Results

The results from the BIPS measurements in KFM12A 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 inserted in Sicada, and the CD-ROM:s stored by SKB.

The RAMAC radar data for KFM12A 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. Differences in data quality can be observed along the borehole. In the range 200 m to 400 m (approximately) the penetration is poor compared to the rest of the hole. This is most probable due to high electrical conductivity of the water, or due to less suitable rock conditions.

A number of minor structures also exist, as indicated in Appendix 1. Some clusters of structures can be noticed, but they are often located so close to each other that it is impossible to distinguish one from the other. This phenomenon is typically seen in the 250 MHz data. 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, e.g. structure number 177.

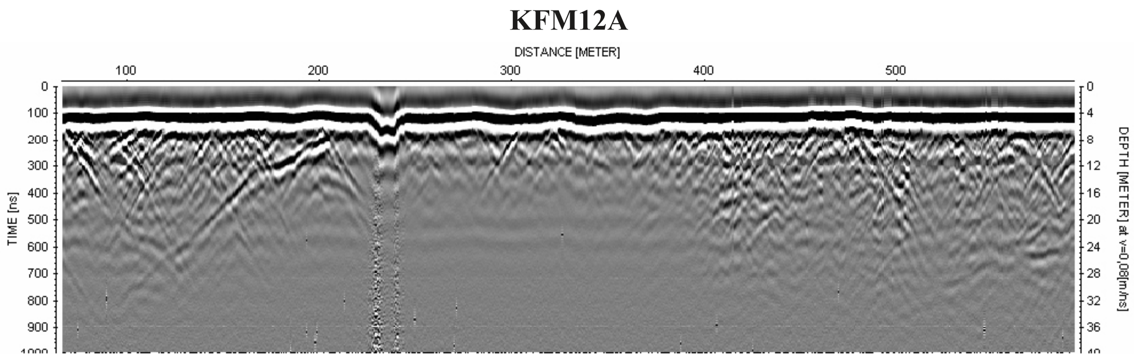


Figure 5-1. *An overview (20 MHz data) of the radar data for the borehole KFM12A. As seen, the radar penetration is slightly reduced from approximately 200 to 400 m borehole length.*

The data quality from KFM12A (as seen in Appendix 1) is satisfying to good, but in some parts of lower quality due to more electrical conductive conditions. An 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. It can probably be concluded that structures that are identified with all three antenna frequencies are quite significant.

In Table 5-1 the distribution of identified structures along the borehole are listed.

Table 5-2 summarises the interpretation of radar data from KFM12A. 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 Table 5-2. 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 denoted 45 and 45x most likely originates from the same geological structure.

In Appendix 1, the amplitude of the first arrival is plotted against the borehole length, for the 250 MHz dipole antenna. 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.

Table 5-1. Number of identified structures as a function of borehole intersection length in KFM12A.

Length (m)	No. of structures
–50	1
50–100	16
100–150	23
150–200	15
200–250	16
250–300	10
300–350	15
350–400	17
400–450	18
450–500	13
500–550	16
550–600	16
600–	4

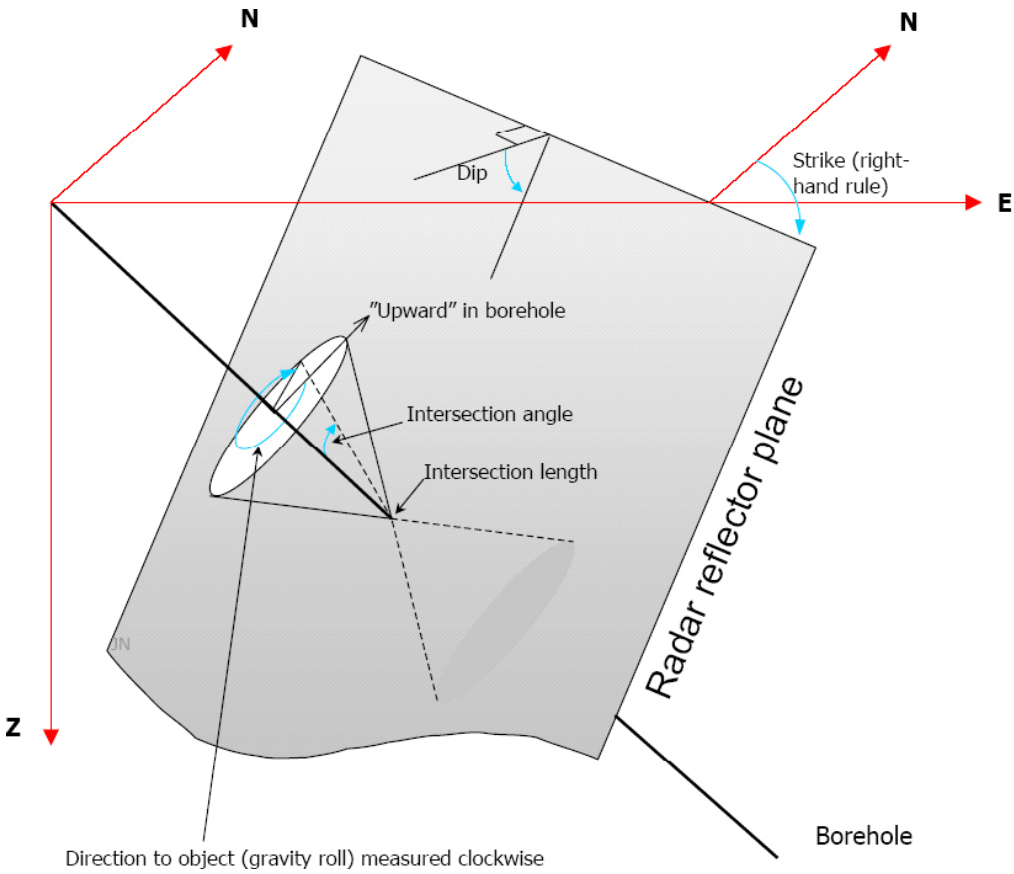


Figure 5-2. *Definition of the direction to a reflector (gravity roll) as presented in Table 5-2.*

Table 5-2. Interpretation of radar reflectors from the dipole antennas 250, 100 and 20 MHz in borehole KFM12A.

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site: **Forsmark**
Borehole name: **KFM12A**
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
172	11.2	49					
156	58.2	51					
155	63.4	85					
1	63.9	72					
2	64.4	54	222	24	37		
3	73.8	50					
4	75.4	41					
5	79.9	50					
6	84.1	59					
7	87.7	59					
173	88.7	48					
12	89.7	55					
10	89.8	65	174	8	141		
8	92.3	66					
9	93.8	54					

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site:	**Forsmark**
Borehole name:	**KFM12A**
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
15	97.0	57					
11	98.7	66					
16	101.4	62					
13	103.9	52					
157	105.3	56					
18	107.4	57					
14	109.3	48					
17	117.6	34	48	77	161		
19	118.1	64					
20	120.3	44					
22	121.6	53					
21	120.3	60					
17x	125.0	22					
28	126.8	70					
23	128.0	83					
24	130.7	43					
25	131.5	75					
26	137.4	72					
174	137.3	56					
158	138.5	63					
34	141.8	49					
27	143.5	63					
35	144.5	48					
159	146.9	53					
32	148.2	71					
29	153.2	60					
31	155.1	36					
30	156.2	51	174 ±	7	271	67	119
33	162.6	54					
36	170.0	45					
38	172.4	33					
37	172.8	45	105	43	192		
39	176.1	66	102	35	171		
40	178.2	50					
42	184.5	43					
41	189.5	48	231	32	34		
43	189.9	82					
44	191.6	51					
160	192.8	39					
178	195.2	53					
46	203.8	59					
48	208.4	46					
47	205.6	46					

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site: Forsmark
Borehole name: KFM12A
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
49	209.9	51					
45x	210.1	28					
50	213.3	51					
51	215.4	48					
52	219.6	48					
53	221.1	48					
54	226.0	52					
161	231.2	35					
57	234.9	53					
55	238.5	48					
56	239.3	43					
59	246.8	29					
58	249.8	64					
45	250.5	14	213	52	345		
60	253.2	75					
61	261.5	61					
62	264.6	52					
63	267.0	46					
64	272.1	53					
65	274.8	58	297 ±	52	86	31	182
66	286.6	57					
67	288.9	53					
68	295.3	62					
69	302.1	54					
70	304.0	61					
72	304.9	51					
77	306.4	38					
71	313.8	52	336	68	105		
73	322.3	53					
74	324.9	54					
75	330.4	62					
162	333.3	37					
76	338.2	52	357 ±	63	119	4	274
78	343.7	61					
79	345.1	56					
163	347.9	55					
81	348.5	58	357 ±	63	119	2	243
80	349.5	49					
82	350.9	50					
83	352.7	47					
84	358.1	57	285 ±	49	78	37	177
85	360.9	48					
86	362.8	38					

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site: **Forsmark**
Borehole name: **KFM12A**
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
87	365.3	54					
88	370.4	52					
89	378.2	59	186 ±	4	353	66	124
90	383.3	45					
91	383.6	51					
92	385.0	55					
169	389.5	45					
93	389.8	54					
94	392.5	67	105	33	161		
164	394.4	50					
165	395.7	50					
95	397.9	69					
96	401.5	71					
97	404.0	74					
166	405.3	74					
99	407.4	59	135 ±	23	178	43	105
98	409.0	77					
100	411.5	64					
101	413.1	57					
102	419.9	66	168 ±	11	145	56	113
103	421.4	65					
104	424.2	57					
107	429.1	54	183 ±	4	325	68	121
167	429.8	62					
105	432.7	47					
108	433.1	56					
106	433.8	53					
109	437.2	54					
110	445.1	56					
111	448.0	62					
112	451.0	76					
113	452.6	52					
114	458.8	60					
115	460.6	59					
116	462.1	58	186	3	38		
117	465.7	53	78	55	167		
118	470.8	56					
119	472.4	59					
120	481.5	62					
170	485.2	59					
121	487.0	54					
122	490.4	55					
123	491.3	59					

RADINTER MODEL INFORMATION
(Directional and dipole antennas)

Site: Forsmark
Borehole name: KFM12A
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
126	504.5	50					
125	505.4	61					
124	506.9	62					
127	515.2	51					
128	517.1	73					
129	517.8	56					
130	522.1	59					
131	525.6	78					
175	529.5	76					
133	532.1	72					
132	533.2	55					
134	535.4	67					
135	538.5	73					
136	537.4	62	330 ±	59	102	16	178
137	542.6	73					
171	548.9	72					
138	552.0	69					
139	553.5	60					
140	557.0	67					
141	558.2	63					
142	559.3	76					
144	560.5	72					
145	565.2	60					
168	568.4	69					
143	569.3	78					
146	572.9	51					
147	574.0	63					
148	582.4	72					
149	581.9	54					
151	587.4	59					
150	590.2	62					
176	595.0	59					
152	601.0	60					
153	604.5	50					
154	607.6	53					
177	1,011.2	5					

Table 5-3. Borehole length intervals in KFM12A with decreased amplitude for the 250 MHz antenna.

Length (m)	Length (m)
65	405
85–90	450
115–155	470
180–195	485–495
210–280	515–540
290–390	

Table 5-4. Some important structures in KFM12A.

Borehole	KFM12A
Structures	17, 17x, 28, 45, 45x, 71, 116, 118, 128, 144, 160 and 172

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.

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 presented in Figure 4-2 in this report.

Values for the inclination and azimuth of the borehole, presented in Appendix 2 in this report, are only preliminary.

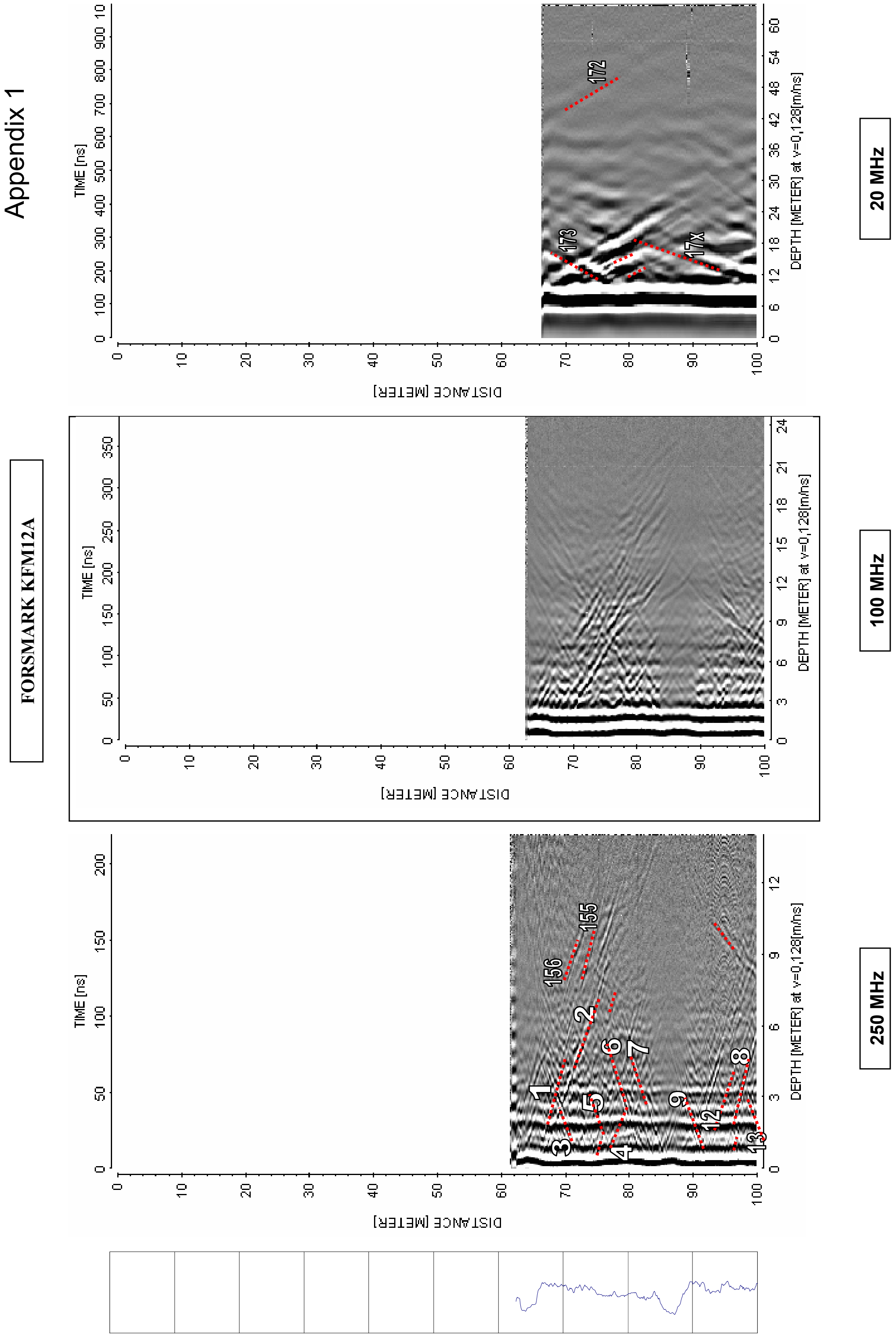
Only one logging run has been performed in KFM12A. This implies that no comparison regarding the uncertainties of the orientation of the probe can be presented.

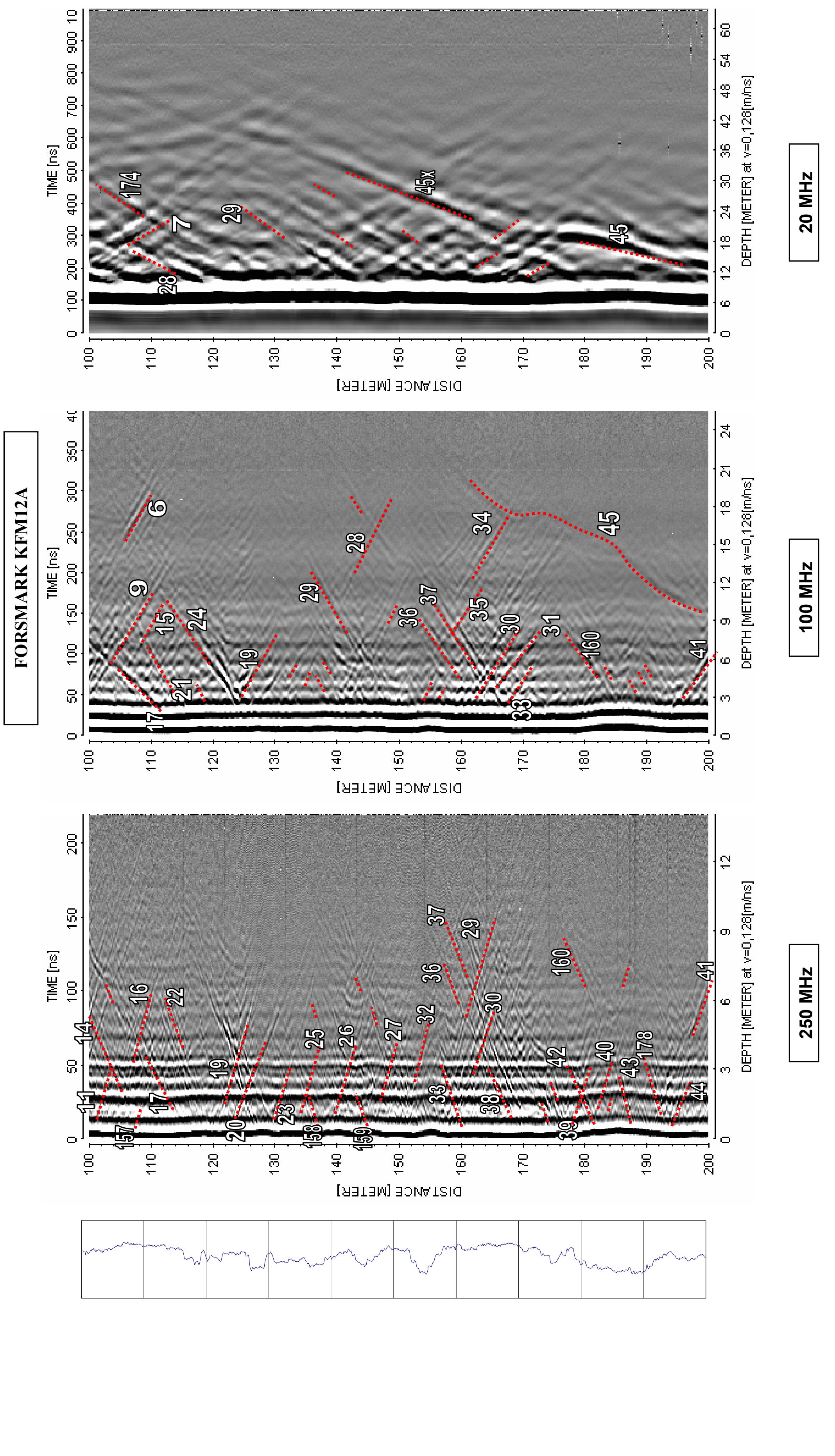
The images are not of perfect quality, mud covers the lower most part of the borehole walls from the start at 61 meter down to the end at 597 meter. Thanks to perfect water quality and lack of discolouring of the borehole walls, the images are interpretable.

References

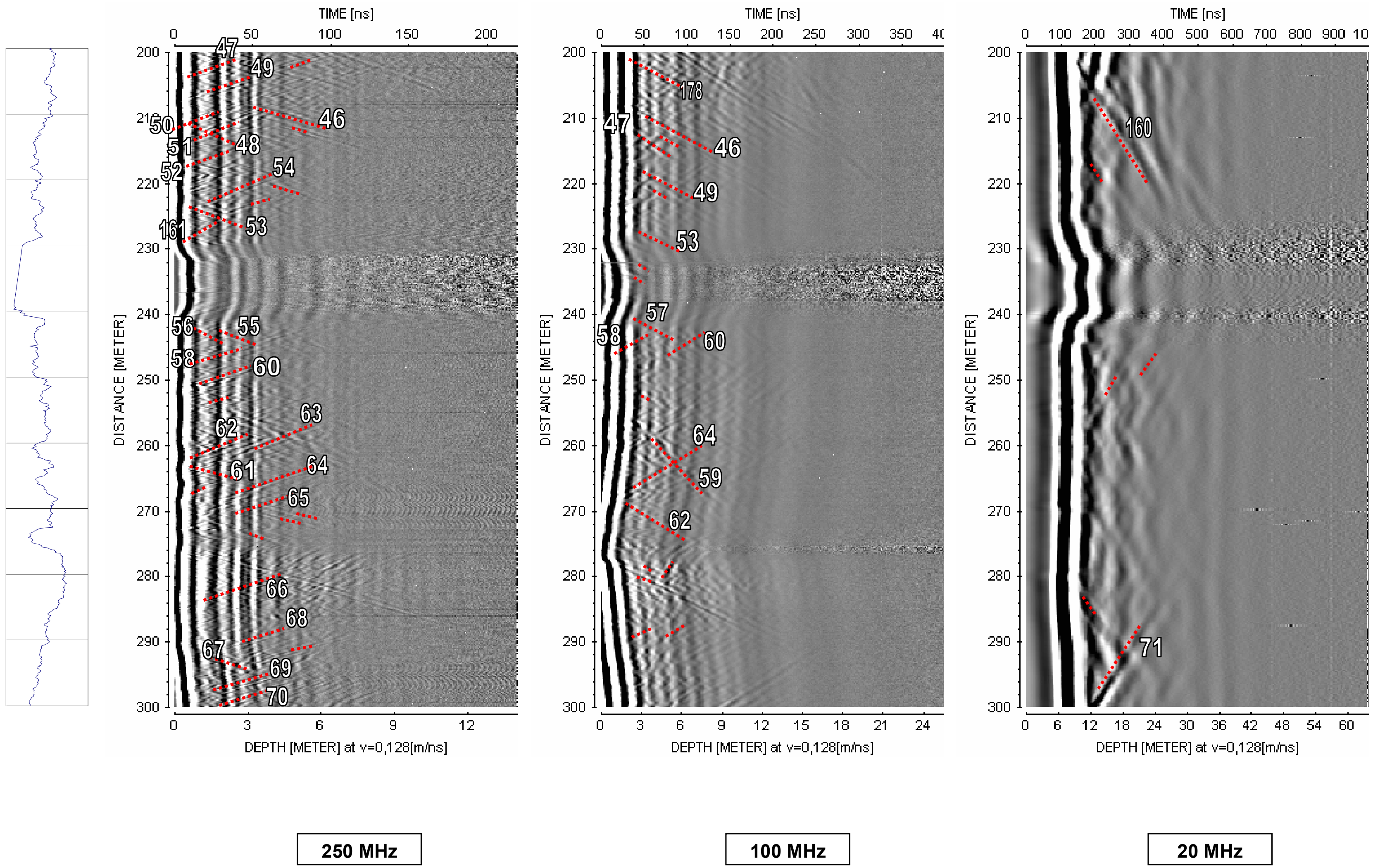
/1/ **Gustafsson C, Nilsson P, 2003.** Geophysical, radar and BIPS logging in boreholes HFM01, HFM02, HFM03 and the percussion drilled part of KFM01A. SKB P-03-39, Svensk Kärnbränslehantering AB.

Radar logging in KFM12A. 60 to 595 m. Dipole antennas 250, 100 and 20 MHz

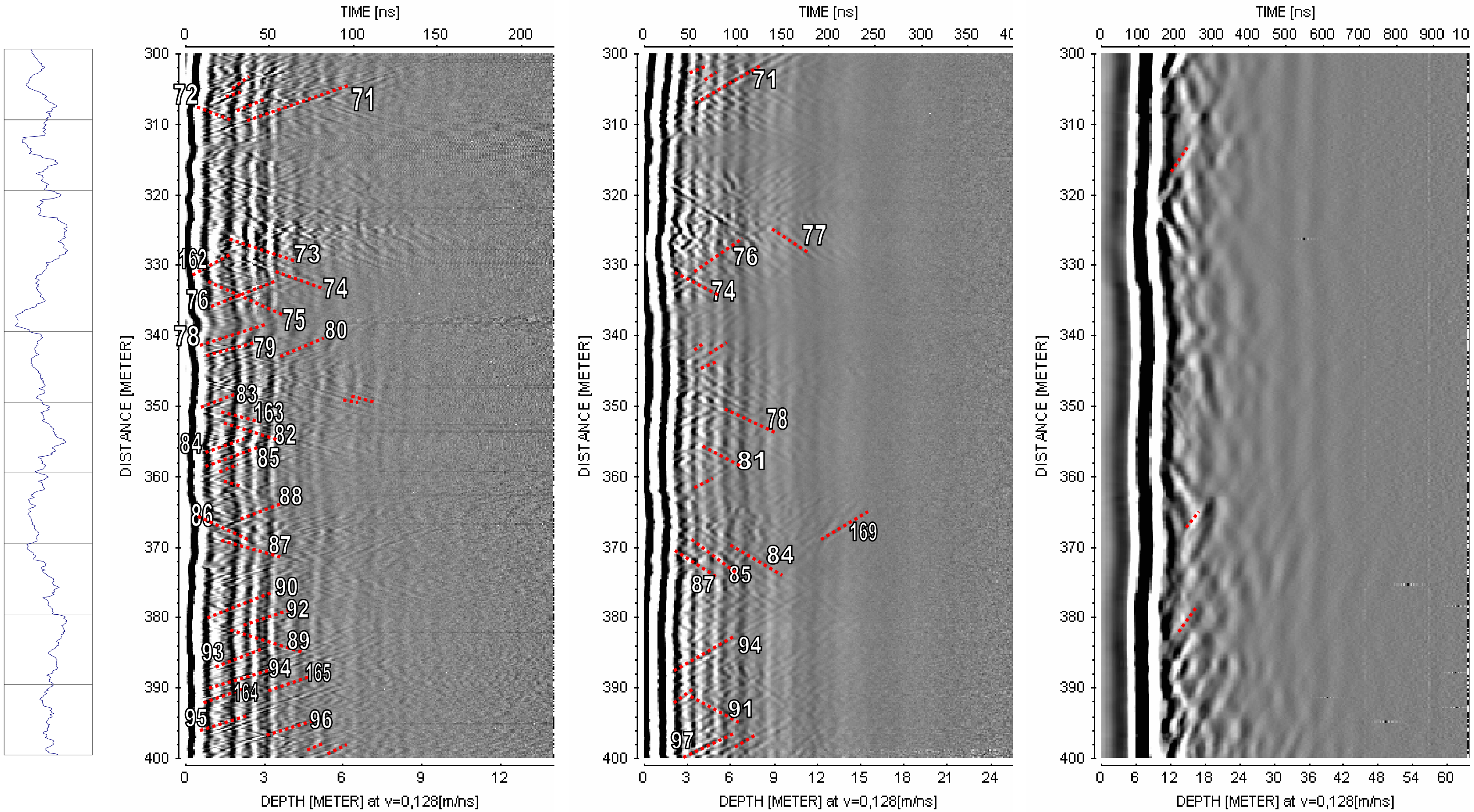



FORSMARK KFM12A
250 MHz
100 MHz
20 MHz
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128[m/ns]

FORSMARK KFM12A

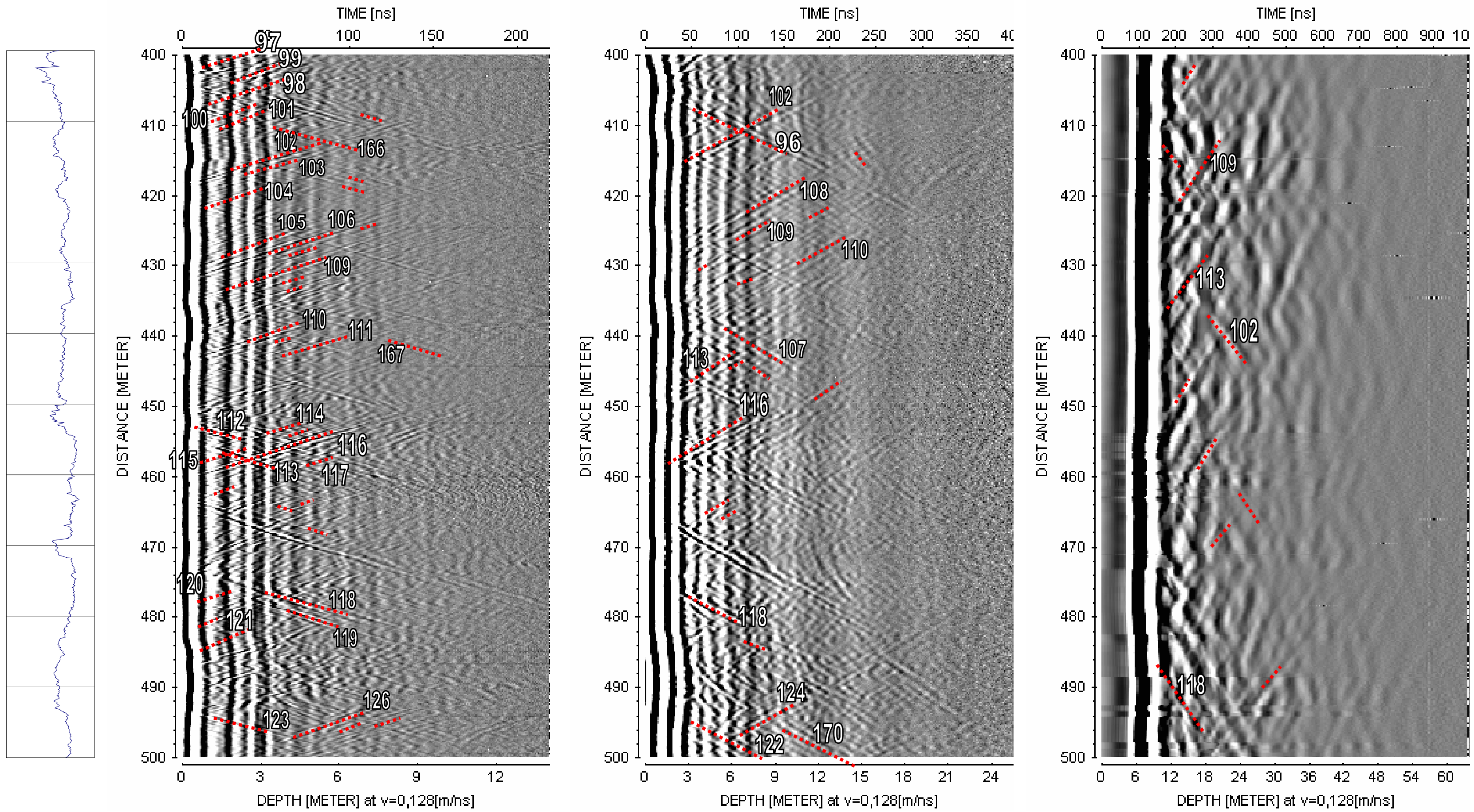


FORSMARK KFM12A



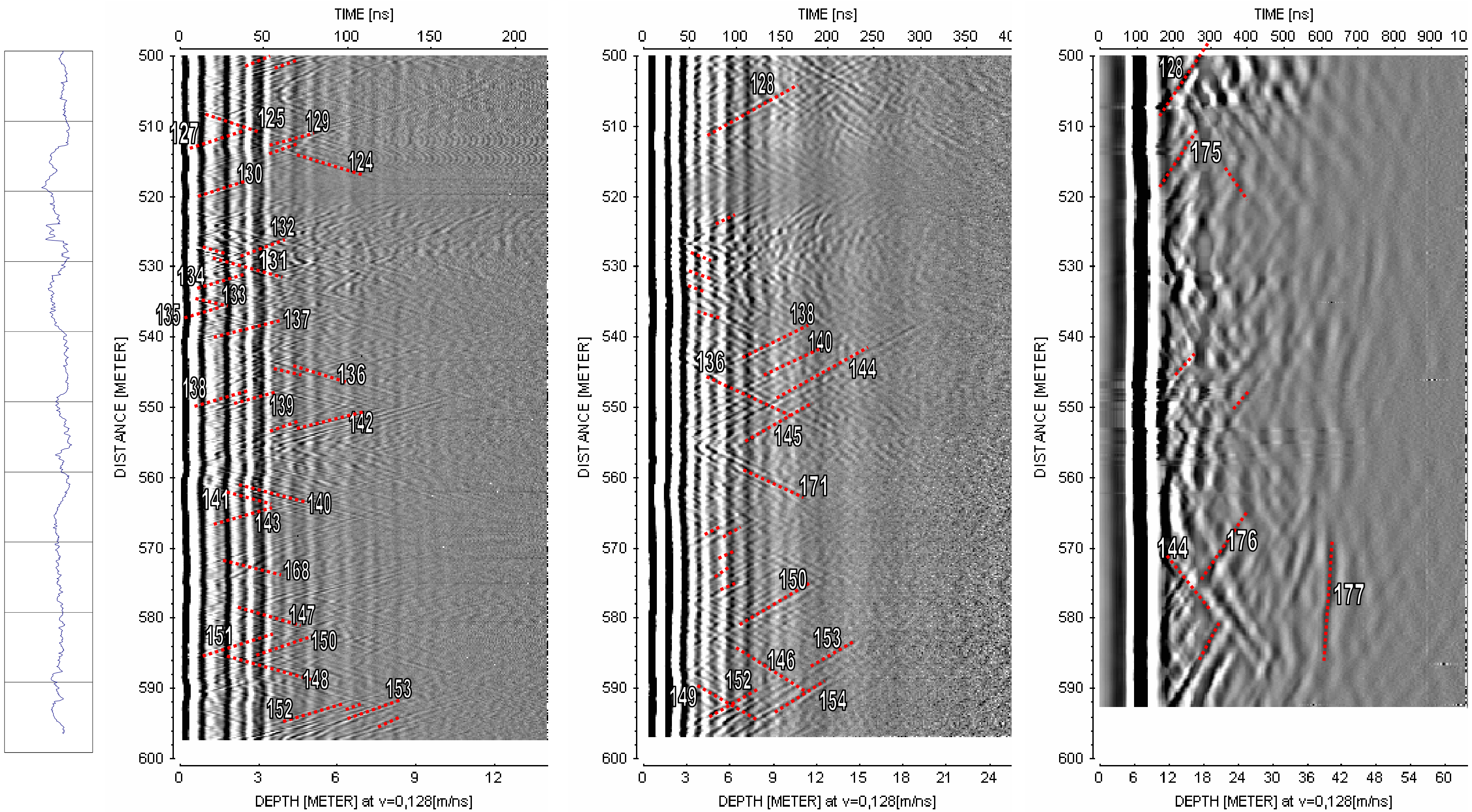
250 MHz **100 MHz** **20 MHz**

FORSMARK KFM12A



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

FORSMARK KFM12A



250 MHz

100 MHz

20 MHz

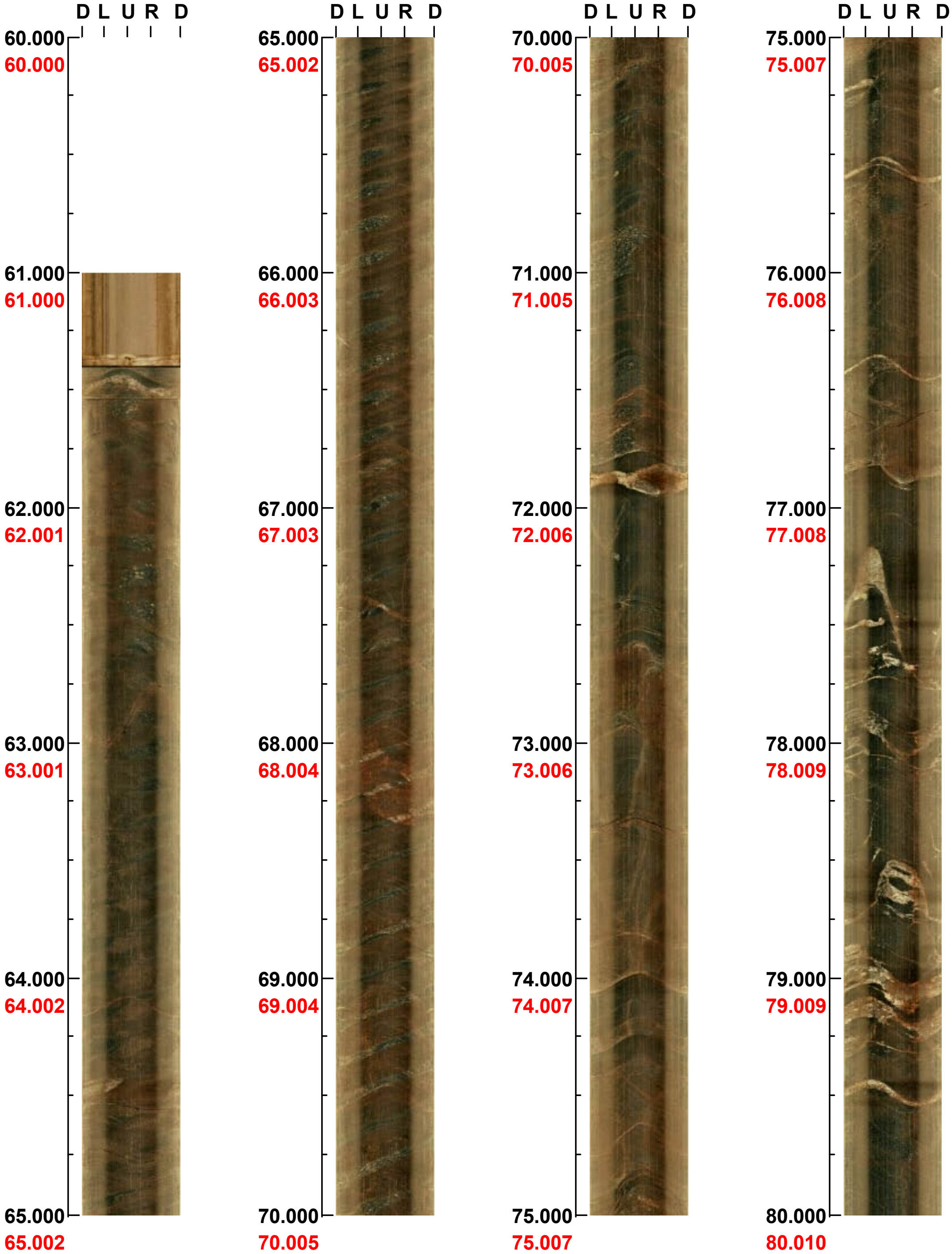
BIPS logging in KFM12A. 61 to 598 m

Project name: Forsmark

Image file	: c:\work\r5605k~1\bips\kfm12a.bip
BDT file	: c:\work\r5605k~1\bips\kfm12a.bdt
Locality	: FORSMARK
Bore hole number	: KFM12A
Date	: 07/03/21
Time	: 12:20:00
Depth range	: 61.000 - 597.630 m
Azimuth	: 36
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	: 27
Color	: +0 +0 +0

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 60.000 - 80.000 m

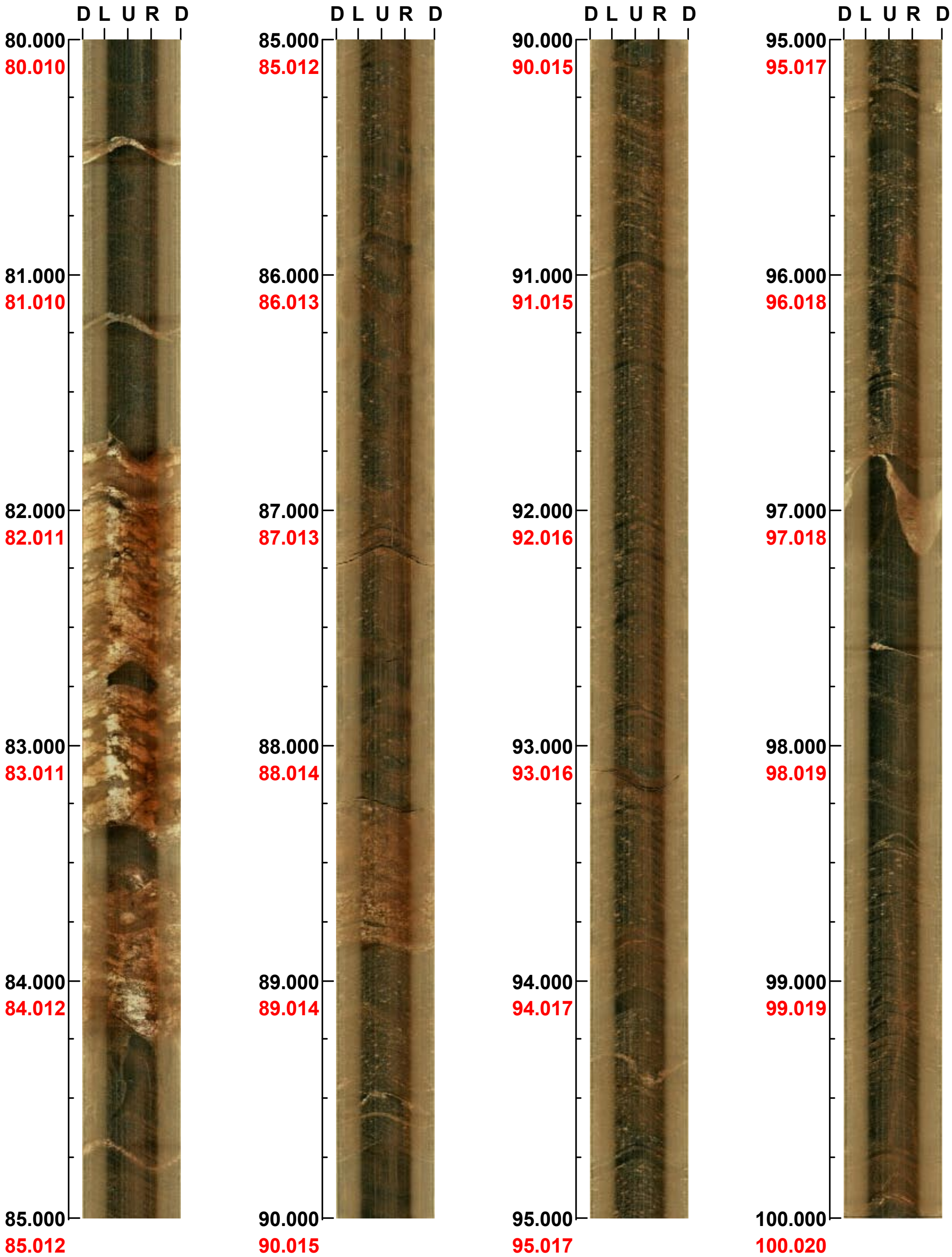


(1 / 27) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Forsmark

Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

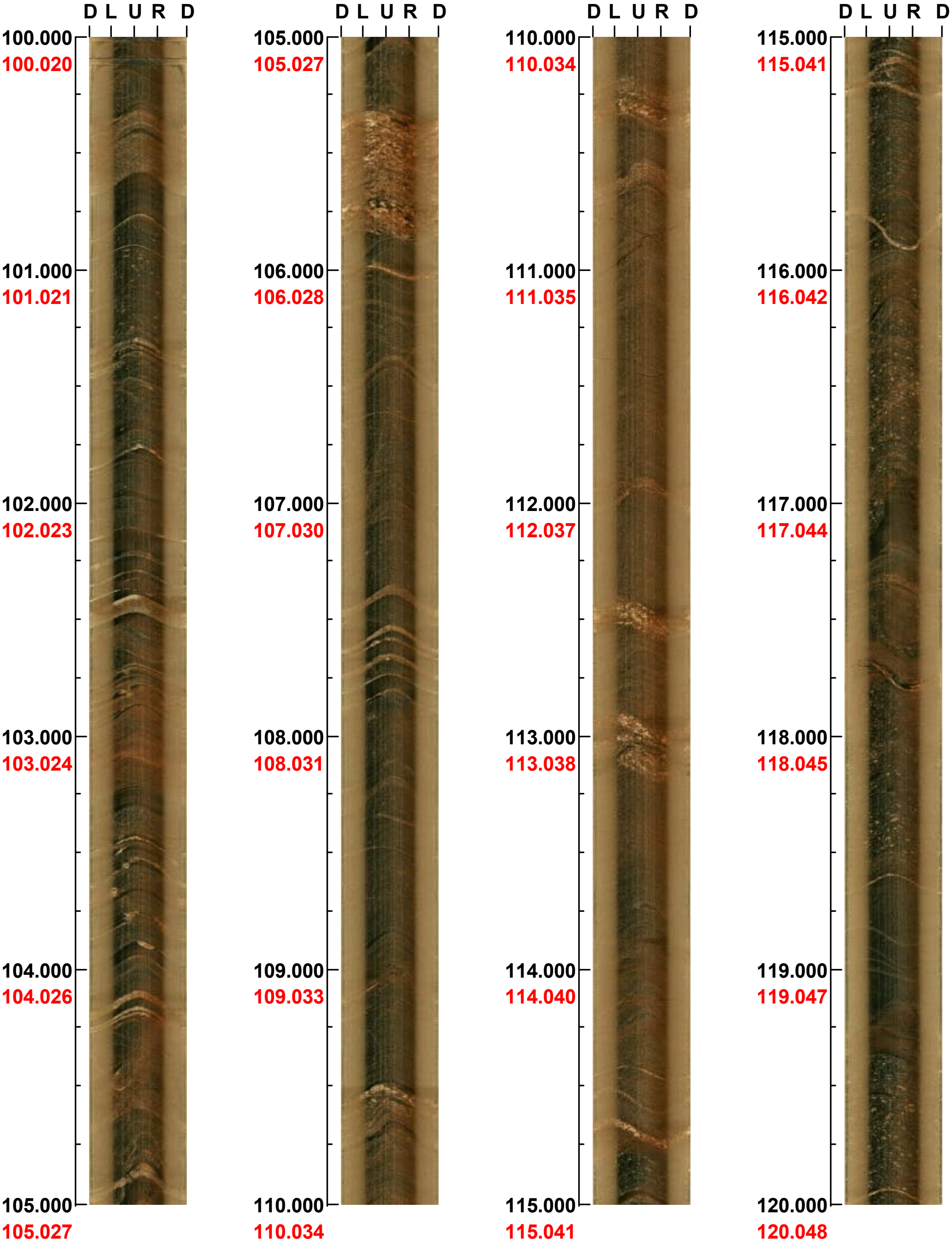
Depth range: 80.000 - 100.000 m



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

Project name: Forsmark
Bore hole No.: KFM12A Azimuth: 36 Inclination: -61

Depth range: 100.000 - 120.000 m



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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 120.000 - 140.000 m

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

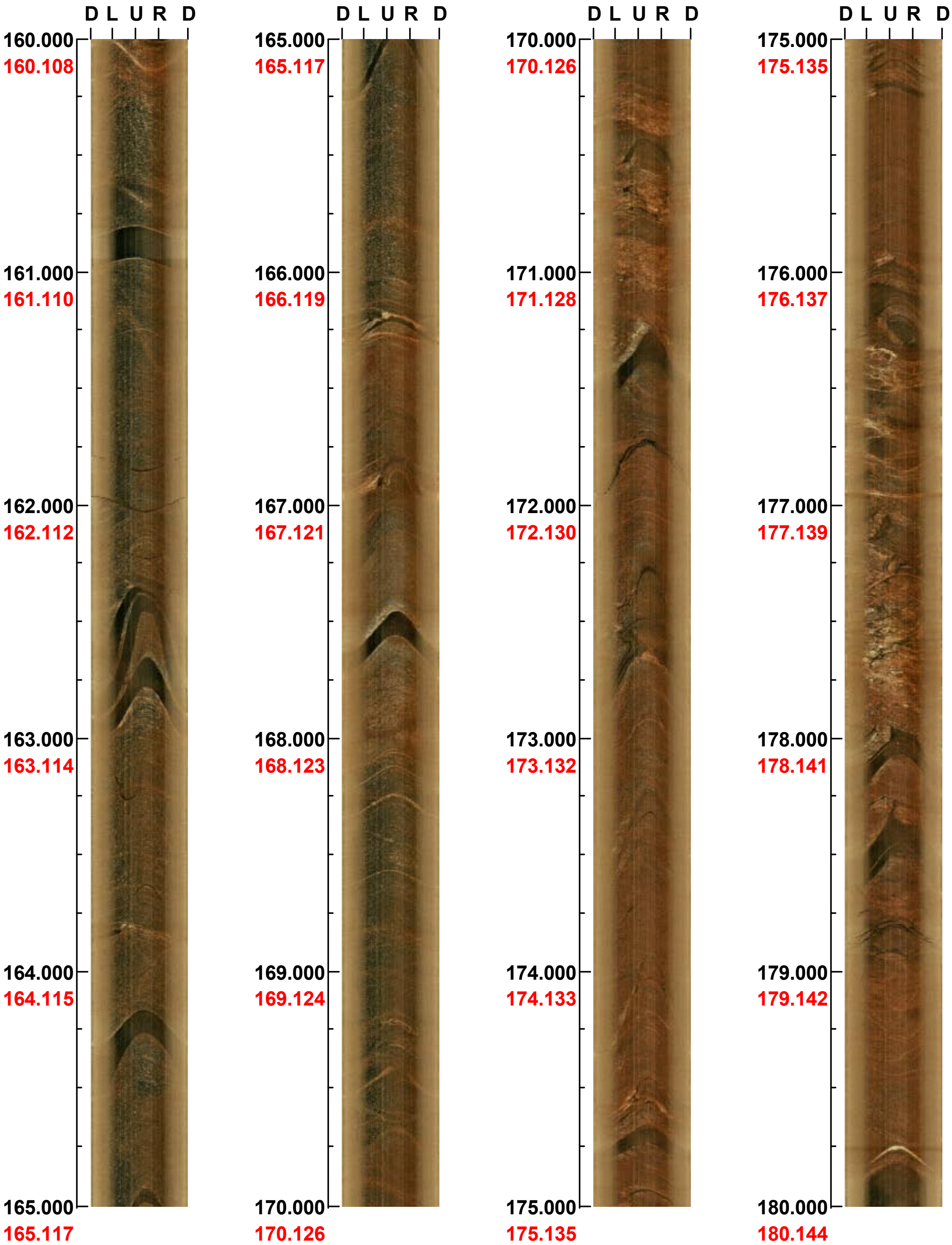
Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 140.000 - 160.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 160.000 - 180.000 m



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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 180.000 - 200.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 200.000 - 220.000 m

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

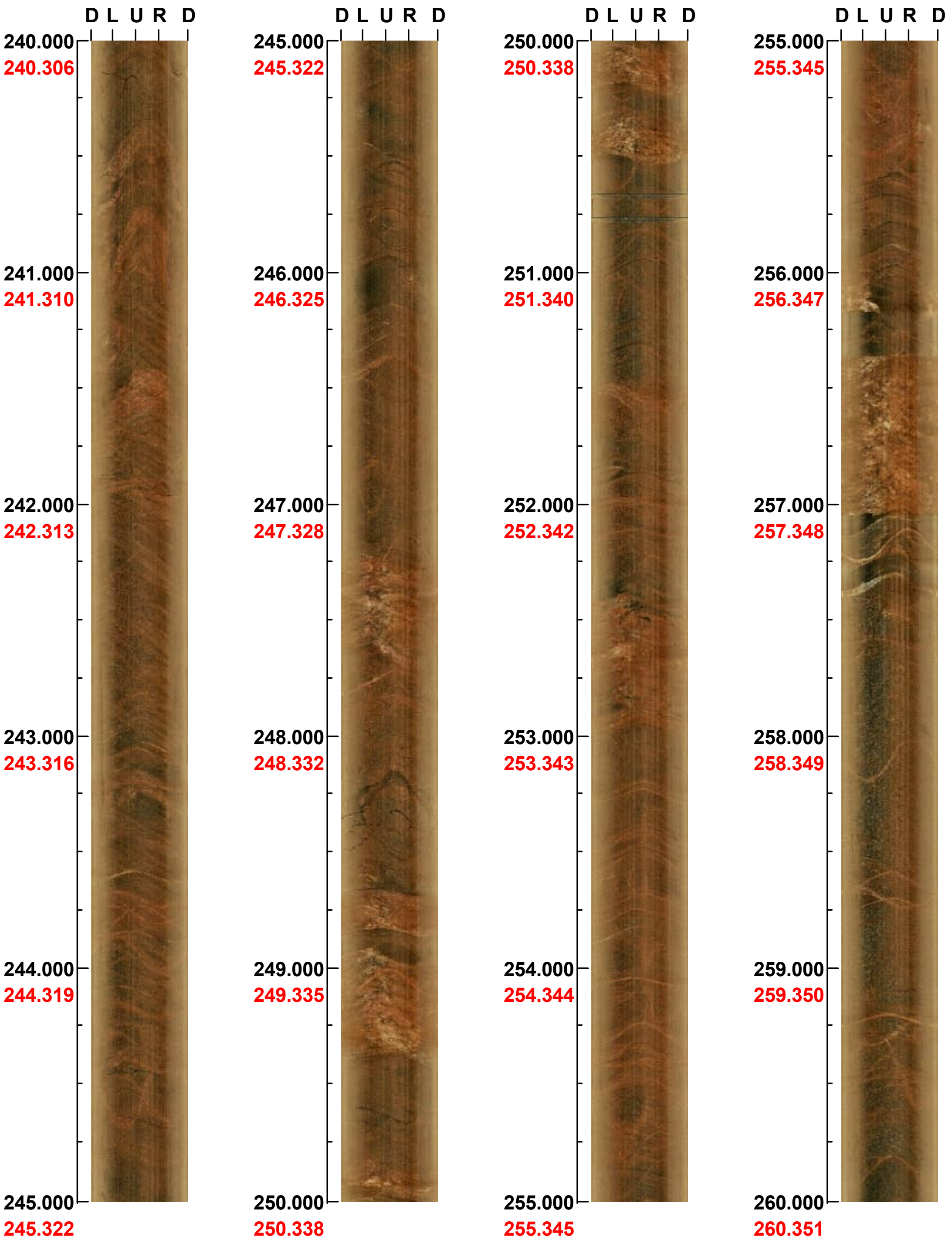
Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 220.000 - 240.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 240.000 - 260.000 m



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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 260.000 - 280.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A Azimuth: 36 Inclination: -61

Depth range: 280.000 - 300.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 300.000 - 320.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A Azimuth: 36 Inclination: -61

Depth range: 320.000 - 340.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 340.000 - 360.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

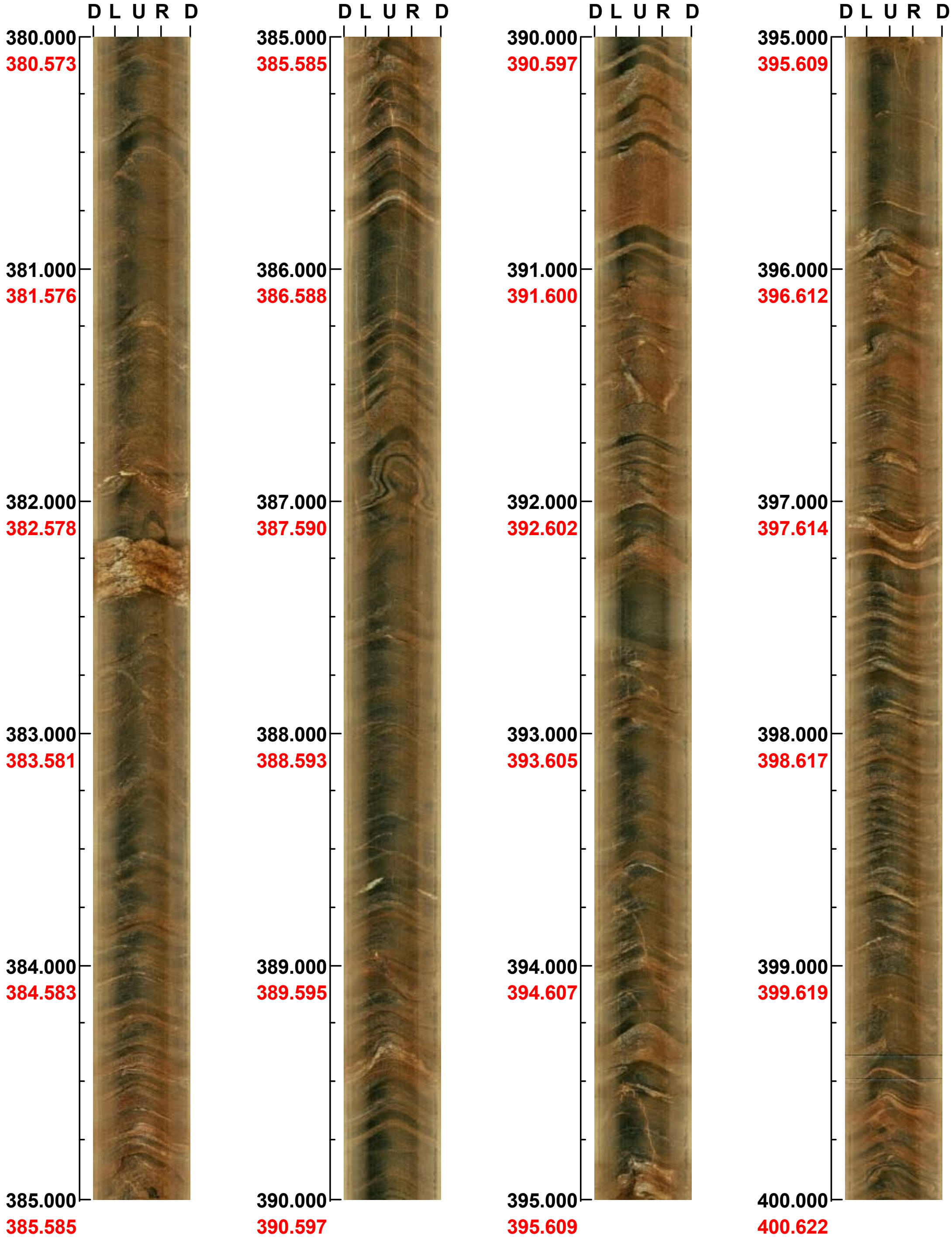
Depth range: 360.000 - 380.000 m

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

Project name: Forsmark

Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 380.000 - 400.000 m



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

Project name: Forsmark
Bore hole No.: KFM12A Azimuth: 36 Inclination: -61

Depth range: 400.000 - 420.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 420.000 - 440.000 m

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

Project name: Forsmark

Bore hole No.: KFM12A Azimuth: 36 Inclination: -61

Depth range: 440.000 - 460.000 m

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

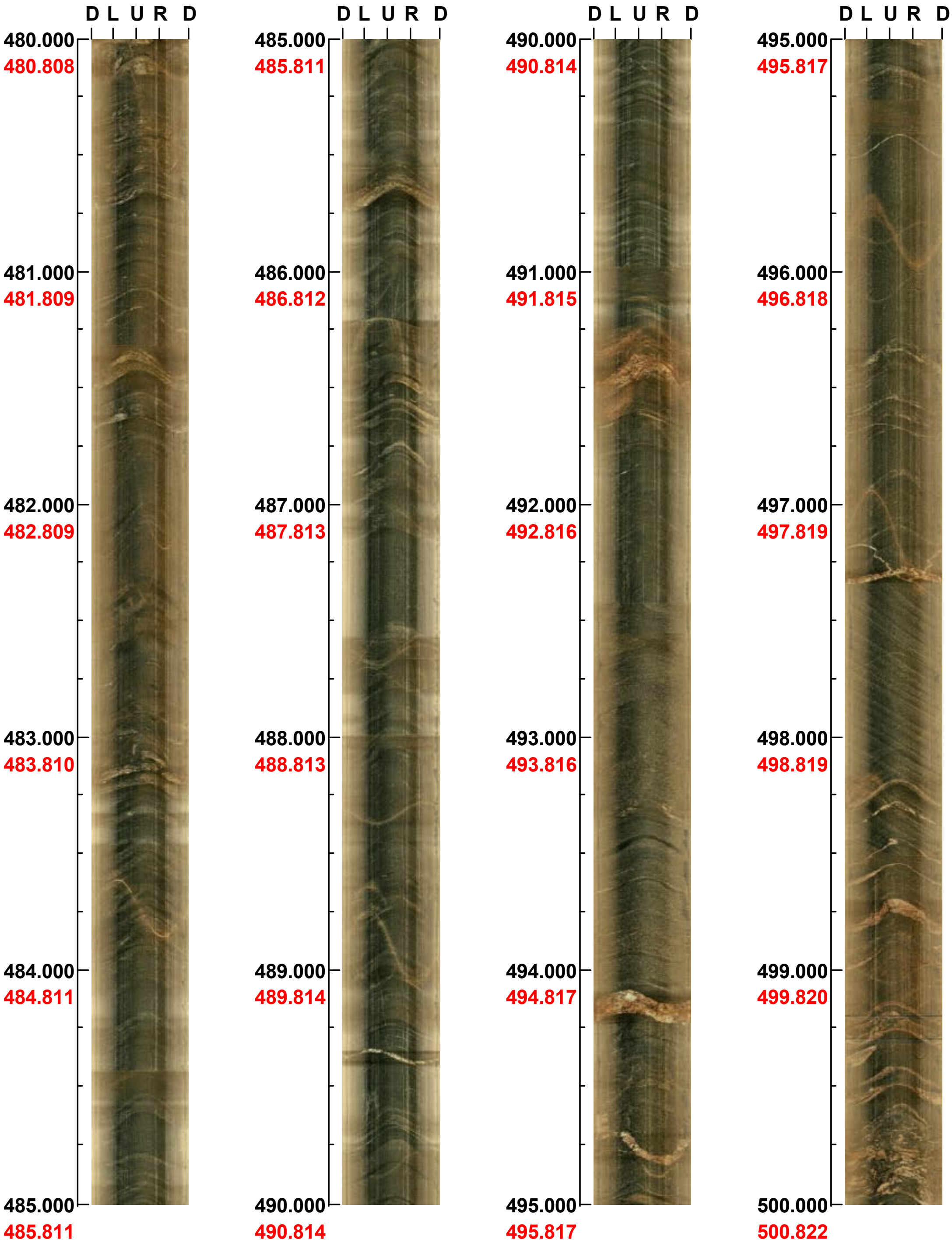
Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 460.000 - 480.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 480.000 - 500.000 m



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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 500.000 - 520.000 m

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

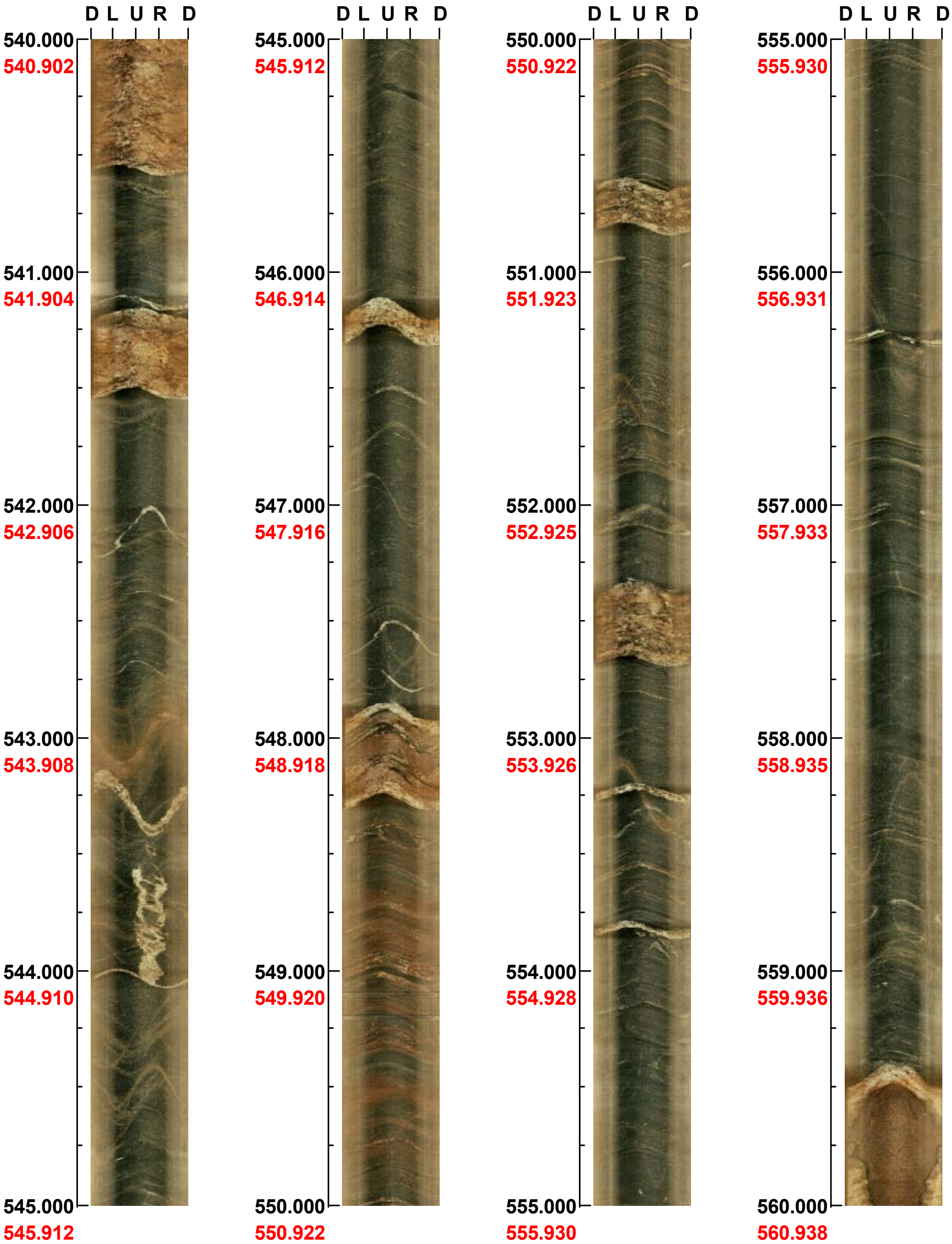
Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 520.000 - 540.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 540.000 - 560.000 m



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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 560.000 - 580.000 m

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

Project name: Forsmark
Bore hole No.: KFM12A **Azimuth: 36** **Inclination: -61**

Depth range: 580.000 - 597.630 m

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