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Forsmark site investigation

RAMAC and BIPS logging in borehole KFM08A

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Malå GeoScience AB/RAYCON

June 2005

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Keywords: BIPS, RAMAC, Radar, TV, Forsmark, AP PF 400-05-030.

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.

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

Reading instructions

The revised version of the report (April 2006) contains a recalculation of the directional radar data. The calculated angles now conforms with the right-hand rule, and they now are measured clockwise.

Abstract

This report includes the data gained in geophysical logging operations performed within the site investigation at Forsmark. The logging operations presented here includes BIPS logging and borehole radar (RAMAC) and in the core-drilled borehole KFM08A. All measurements were conducted by Malå Geoscience AB/RAYCON during May 2005.

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

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

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

The borehole radar data quality from KFM08A was satisfying, but in some minor parts of lower quality due to more conductive conditions. This conductive environment of course reduces the possibility to distinguish and interpret possible structures in the rock mass which otherwise could give a reflection. However, almost 250 reflectors were identified in KFM08A, and around 45 of them oriented.

The basic conditions of the BIPS logging for geological mapping and orientation of structures are satisfying for borehole KFM08A. Mud covering the lower most part of the borehole walls limits the visibility in the bottom of the borehole. The discoloring effect from the drilling is partly affecting the visibility of the wall along the borehole.

Sammanfattning

Denna rapport omfattar geofysiska loggningar inom platsundersökningsprogrammet för Forsmark. Mätningarna som presenteras här omfattar BIPS-loggningar i borrhålen KFM08A. Alla mätningar är utförda av Malå Geoscience AB/RAYCON under maj 2005.

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

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

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

Borrhålsradardata från KFM08A var tillfredställande, men i delar av sämre kvalité troligen till stor del beroende på en konduktiv miljö. En konduktiv miljö minskar möjligheterna att identifiera strukturer från borrhålsradardata. Dock har närmare 250 radarreflektorer har identifierats i KFM08A, varav cirka 45 är orienterade.

BIPS-bilderna visar att förutsättningarna för geologisk kartering och sprickorientering är goda för KFM08A. Det är dock en del lösa mineralpartiklar i vattnet som lägger sig på liggsidan i borrhålet och på så sätt försämrar kvalitén på bilderna under de sista hundra metrarna av borrhålet. Missfärgningen från borrningen är i vissa delar av borrhålet betydande och försämrar möjligheterna för karteringen.

Contents

1 Introduction

This document reports the data gained in geophysical logging operations, which is one of the activities performed within the site investigation at Forsmark. The logging operations presented here includes borehole radar (RAMAC) and TV-logging (BIPS) in the core-drilled borehole KFM08A. The work was carried out in accordance with Activity plan AP PF 400-05-030. 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 100 to approximately 1,000 m in borehole KFM08A. The borehole is drilled with a diameter of approximately 76 mm.

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

The used investigation techniques comprised:

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

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

Activity plan	Number	Version
BIPS- och radarloggning i KFM08A	AP PF 400-05-030	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för TV-loggning med BIPS	SKB MD 222.006	1.0
Metodbeskrivning för borrhålsradar	SKB MD 252.020	1.0

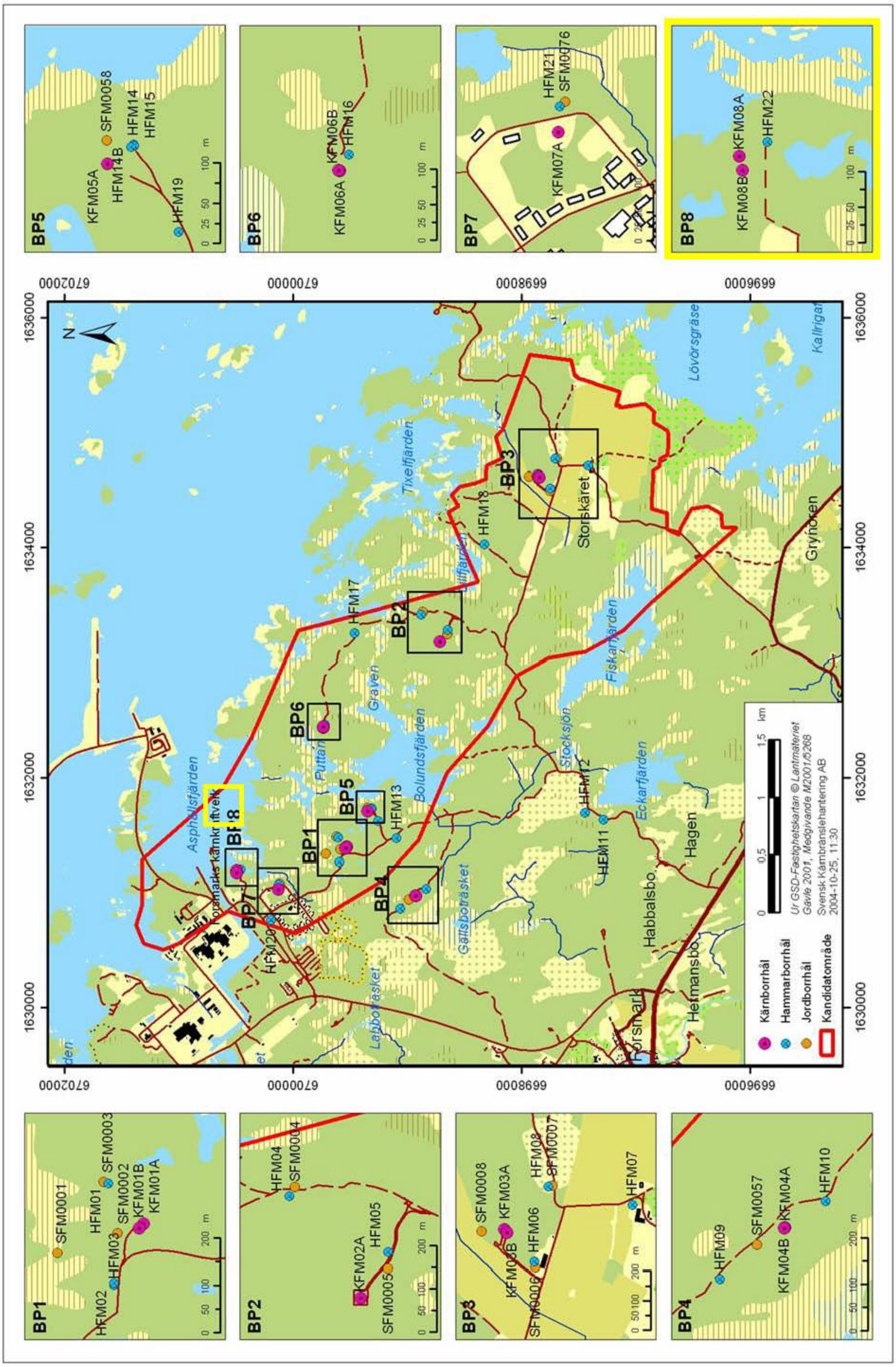


Figure 1-1. *General overview over the Forsmark area with the location of the borehole KFM08A at drill site BP8.*

2 Objective and scope

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

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

3 Equipment

3.1 Radar measurements RAMAC

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

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

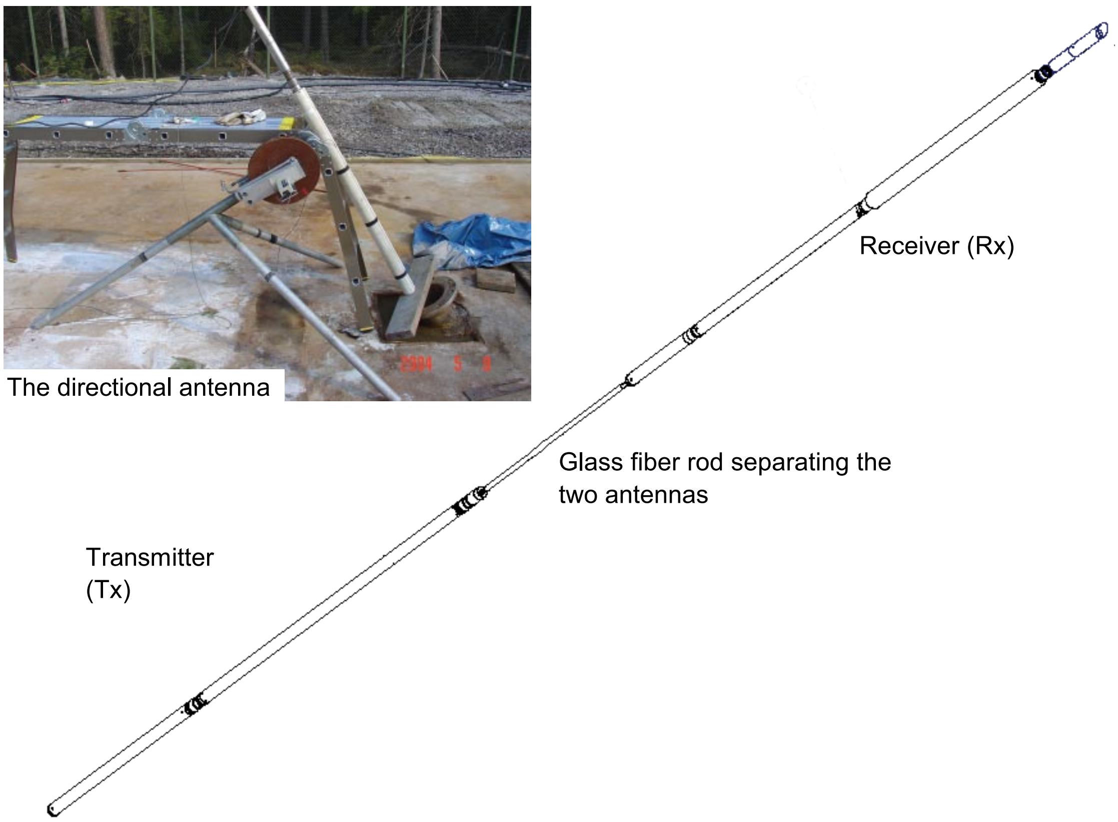


Figure 3-1. *Example of a borehole radar antenna.*

3.2 TV-Camera, BIPS

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

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

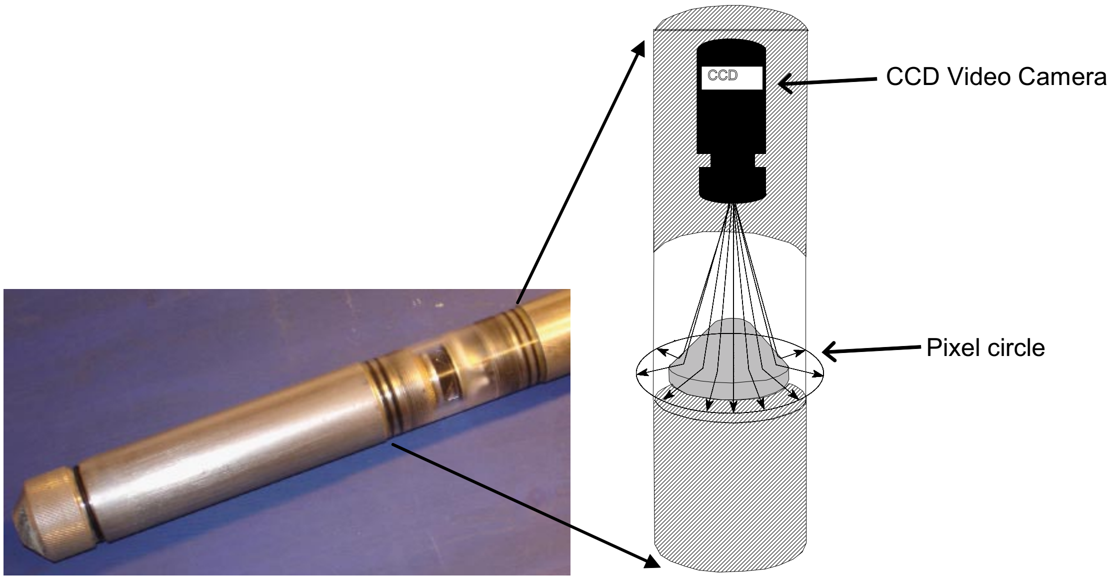


Figure 3-2. *The BIPS-system. To the right an illustration of the conical mirror scanning.*

4 Execution

4.1 General

4.1.1 RAMAC Radar

The measurements in KFM08A were carried out with dipole radar antennas, with frequencies of 250, 100 and 20 MHz. The directional antenna was also used, with a central frequency of 60 MHz.

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

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

The functionality of the directional antenna was tested before measurements in KFM08A. This is done by measurements in the air, where the receiver antenna and the transmitter antenna are placed apart. While transmitting and measuring, the receiver antenna is turned around and by that giving the direction from the receiver antenna to the transmitter antenna. The difference in direction measured by compass and the result achieved from the directional antenna was about 8°. This can be considered as very good due to the disturbed environment, with metallic objects etc at the test site.

For more information on system settings used in the investigation of KFM08A see Table 4-1.

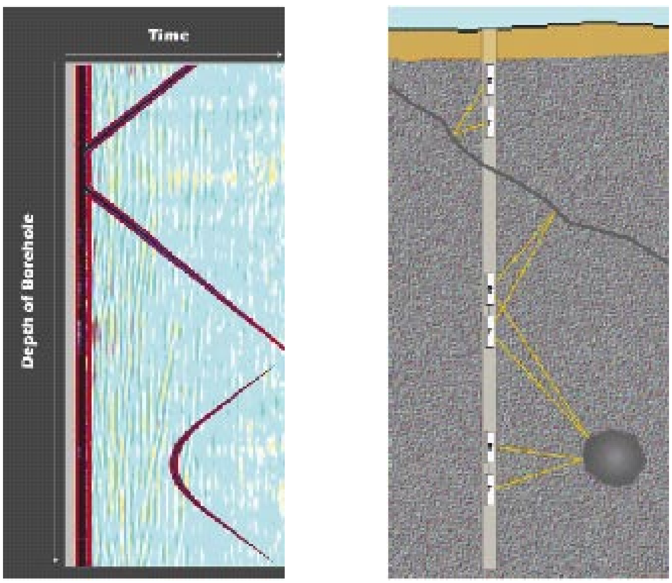


Figure 4-1. *The principle of radar borehole reflection survey and an example of result.*

Table 4-1. Radar logging information from KFM08A.

Site:	**Forsmark**	**Logging company:**	**RAYCON**		
BH:	**KFM08A**	**Equipment:**	**SKB RAMAC**		
Type:	**Directional/Dipole**	**Manufacturer:**	**MALÅ GeoScience**		
Operator:	**CG**	**Antenna**			
		Directional	**250 MHz**	**100 MHz**	**20 MHz**
	Logging date:	05-05-11	05-05-10	05-05-10	05-05-10
	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	603
	Number of stacks:	32	Auto	Auto	Auto
	Signal position:	410.5	–0.34	–0.35	–1.46
	Logging from (m):	103.4	101.5	102.6	106.25
	Logging to (m):	917.4	990	9,939	986.2
	Trace interval (m):	0.5	0.25	0.2	0.1
	Antenna separation (m):	5.73	1.9	2.9	10.05

4.1.2 BIPS

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

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

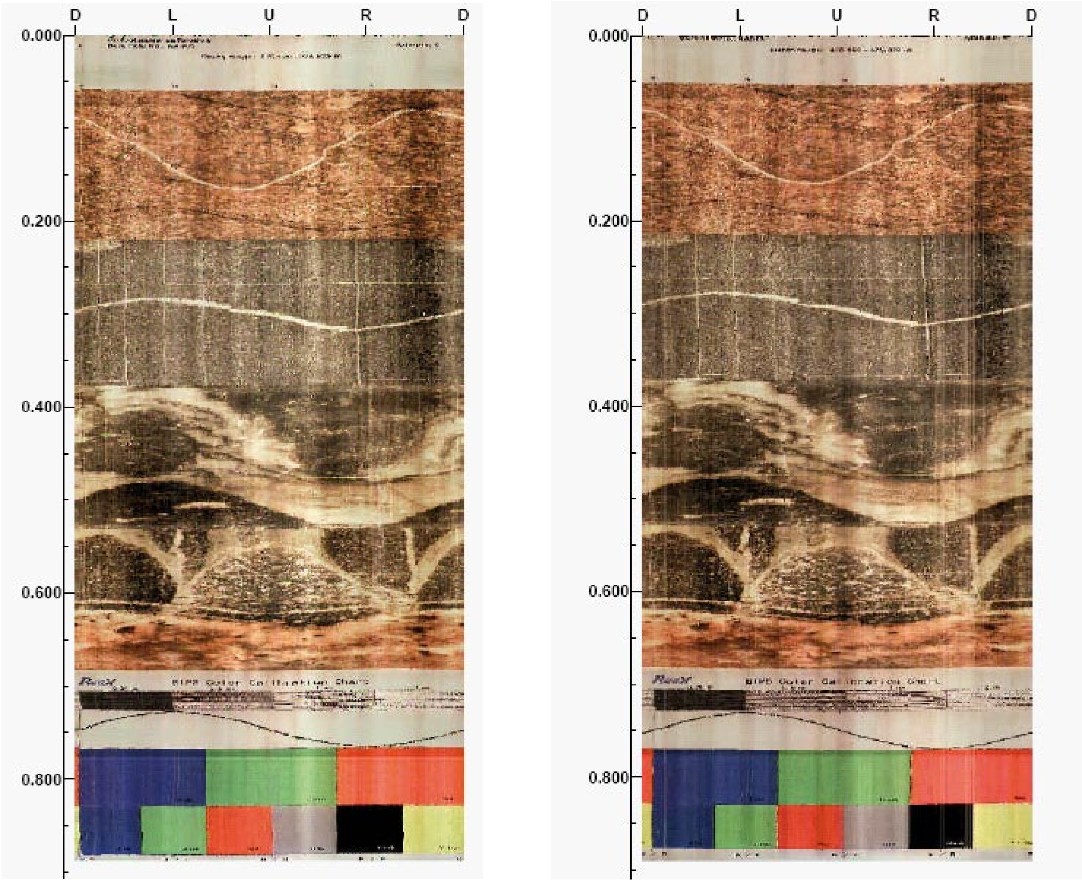
In order to control the quality of the system, calibration measurements were performed in a test pipe before logging the first borehole and after logging the last one. Figure 4-2 corresponds to the test pipe logging before and after the logging of KFM08A in May. The results showed no difference regarding 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 2 in this report.

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, where the reference marks in the borehole wall is visible on the image, the position where the depth 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 depth mark visible in the BIPS image. The adjusted true length is marked with red in the image plot together with the non-adjusted measured length, which is marked with black as seen in Appendix 2. The tape marks on the logging cable are then used for controlling the RAMAC measurement.



Before After

Figure 4-2. Results from logging in the test pipe before and after the logging campaign in May (2005-05-09).

The experience we have from earlier measurements with dipole antennas in the 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.

The results from KFM08A, the depth to identified structures, are corrected according to the present depth divergence, as stated in the field notes, delivered to SKB/SICADA. The correction is done by a change in the radar information file, *.rad.

4.2 Analyses and interpretation

4.2.1 Radar

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

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

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

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

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

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

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

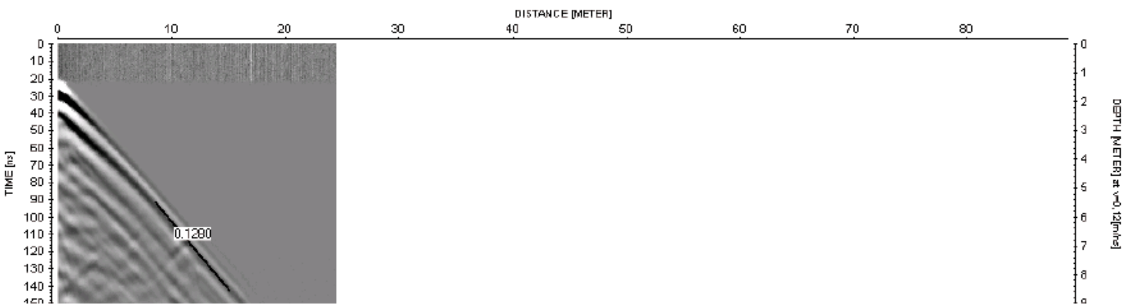


Figure 4-3. *Results from velocity measurements in HFM03 /1/.*

Table 4-2. Processing steps for borehole radar data from KFM08A.

Site:	**Forsmark**		**Logging company:**	**RAYCON**	
BH:	**KFM08A**		**Equipment:**	**SKB RAMAC**	
Type:	**Directional/Dipole**		**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JA**		**Antenna**		
		Directional	**250 MHz**	**100 MHz**	**20 MHz**
Processing:		DC adjustment	DC removal	DC removal	DC removal
		(400–500)	(200–250)	(450–520)	(2,000–2,400)
		Time gain	Move start time	Move start time	Move start time
		(Linear 50, exp 1)	(–15)	(–36.6)	(–132)
		FIR	Gain	Gain	Gain
		(15/5)	(from 12, linear 2, exp 1)	(from 45, linear 2.5, exp 0.4)	(from 100, linear 2.5, exp 0.01)

4.2.2 BIPS

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

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

4.3 Nonconformities

The logging with the directional antenna stopped at a depth of 915 m because of jamming of the probe. Some attempts to pass this section were performed but after contact with the activity manager at the site, the decision was made to stop logging. The great risk of getting stuck with the antenna in the known fracture zone was too high compared with the relatively bad results we got due to a quite high salinity of the water.

The revised version of the report (April 2006) contains a recalculation of the directional radar data. The calculated angles now conforms with the right-hand rule, and they now are measured clockwise.

5 Results

The results from the BIPS measurements in KFM08A 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 KFM08A was delivered as raw data (file format *.rd3 or *.rd5) with corresponding information files (file format *.rad) on CD-ROM's to SKB before the field crew left the investigation site, whereas the data processing steps and results are presented in this report. Relevant information, including the interpretation presented in this report, was inserted into the SKB database SICADA.

5.1 RAMAC logging

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

Only the larger clearly visible structures are interpreted in RadinterSKB. A number of minor structures or other also exist. It should also be pointed out that reflections interpreted will always get an intersection point with the borehole, but being located further away, they may in some cases not reach the borehole. Parallel structures can also be identified, especially in the 20 MHz data. An overview of KFM08A (20 MHz data) is given in Figure 5-1 below, showing several large-scale structures, especially between 100 and 350 m depth. Some indications of parallel structures are also seen between 600 and 750 m, quite close to the borehole. Also seen in Figure 5-1 is the decrease in radar wave penetration at 500 m, indicating a more conductive environment below.

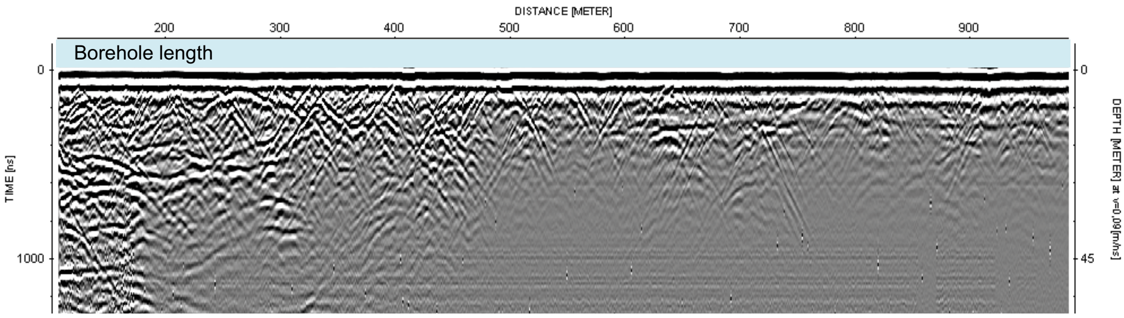


Figure 5-1. *Results from KFM08A, 20 MHz data.*

Also, observe the hyperbola shaped structure at a depth of 160 m in Appendix 1, in the 250 and 100 MHz data. This is most probably due to a point object or a cross section of several fractures. The structure is probably quite small, as it is not indicated in the 20 MHz data, which has a larger wavelength and by that cannot detect smaller objects.

The data quality from KFM08A, (as seen in Appendix 1) is good, 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. A conductive environment of course also reduces the possibility to distinguish and interpret possibly 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.

In parts with an increased conductivity and thereby a decreased depth penetration most often only the edges of structures can be distinguished, giving an intersection angle of 90°. This is especially seen between 760 and 860 m in the 250 MHz data.

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

In Table 5-1 below, the distribution of identified structures along the boreholes KFM08A is showed.

Table 5-1. Identified structures as a function of depth in KFM08A.

Depth (m)	No of structures
–100	2
100–150	18
150–200	13
200–250	18
250–300	7
300–350	15
350–400	16
400–450	14
450–500	20
500–550	13
550–600	16
600–650	13
650–700	14
700–750	15
750–800	8
800–850	10
850–900	10
900–950	11
950–	13

Table 5-2 summarises the interpretation of radar data from KFM08A. In the table the depth and intersection angle to the identified structures are listed. As seen some radar reflectors are marked with ±, which indicates an uncertainty in the interpretation of direction. The direction can in these cases be ± 180°. The direction to the object (the plane) is defined in Figure 5-2. Also the strike and dip of the plane are calculated.

Observe that a structure can have several different angles, if the structure is undulating, and thereby also different intersection depths. This is seen for structure 71 in Table 5-2. To this structure, most likely, also structures 71× belongs.

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

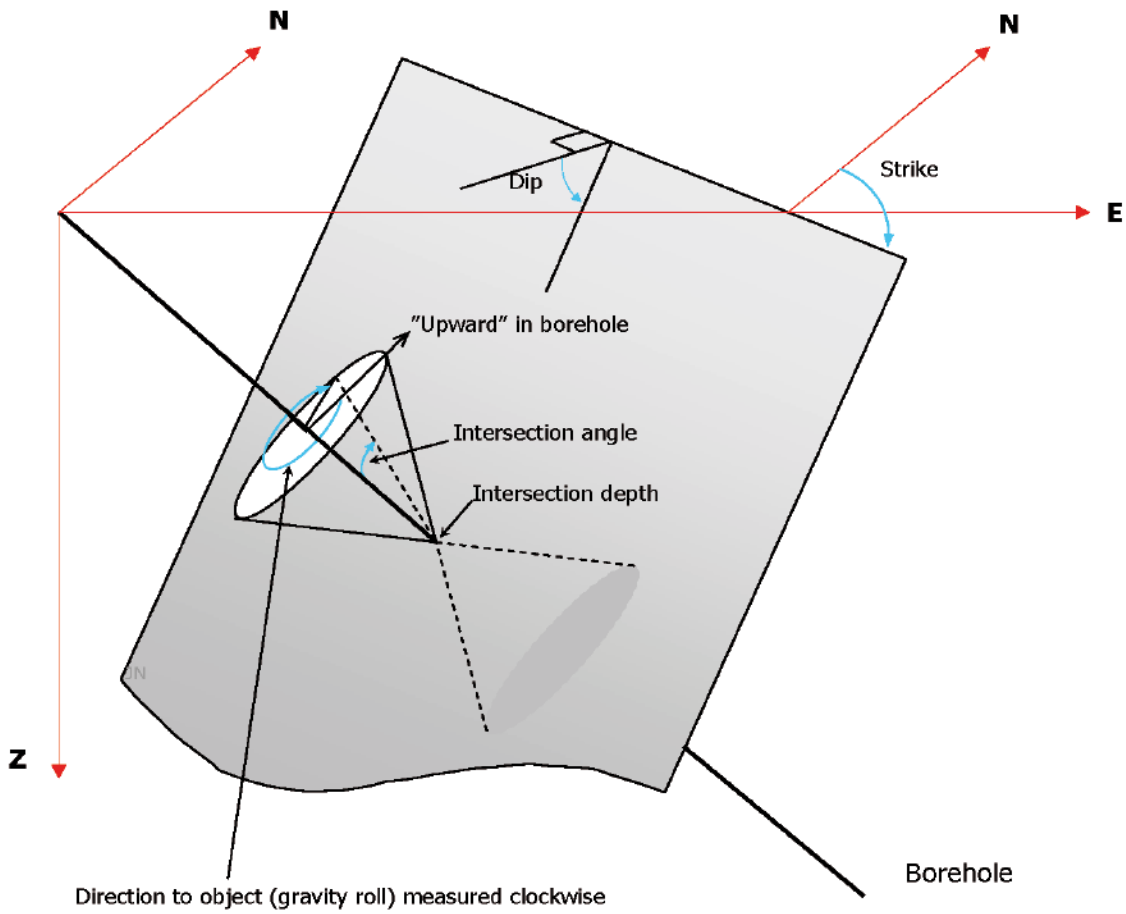


***Figure 5-2.** Definition of object direction, strike and dip as presented in Table 5-2.*

Table 5-2. Interpretation of radar reflectors from dipole antennas 20, 100 and 250 MHz and the directional antenna in borehole KFM08A.

RADINTER MODEL INFORMATION

(20, 100 and 250 MHz Dipole Antennas and Directional antenna)

Site: Forsmark

Borehole name: KFM08A

Nominal velocity (m/μs): 128.0

Name	Intersection depth	Intersection angle	Object direction	Dip 1	Strike 1	Dip 2	Strike 2
217	44.4	48					
232	82.0	32	186	25	249		
1	100.3	66					
2	106.9	71					
216	107.7	34					
3	110.6	67					
4	115.6	67					
5	117.7	61					
6	120.4	77					
7	120.6	56	330	69	38		
8	122.1	76					
9	124.6	80					
10	128.4	35					
16	129.3	78					
11	130.8	34					
12	132.0	55					
13	134.6	75					
14	136.1	53					
15	141.9	50					
17	144.6	69					
18	152.5	64					
19	166.9	41					
20	174.2	45					
21	179.0	47					
22	181.7	49					
26	185.1	57					
23	185.5	49					
24	187.8	58					
25	190.1	58	33	62	76		
27	193.8	61					
28	194.8	54					
29	197.3	53					
30	198.3	58	189	5	319		
184	200.5	53					
31	202.3	60	348	67	50		
32	211.2	43					
33	211.5	55					
34	215.4	63					
235	217.9	12	264	76	332		

RADINTER MODEL INFORMATION

(20, 100 and 250 MHz Dipole Antennas and Directional antenna)

Site:	**Forsmark**
Borehole name:	**KFM08A**
Nominal velocity (m/μs):	**128.0**

Name	Intersection depth	Intersection angle	Object direction	Dip 1	Strike 1	Dip 2	Strike 2
35	221.0	39					
36	221.0	43					
35×	221.3	45					
37	224.4	45	357±	77	55	10	225
39	229.5	43					
38	229.6	34	306	78	14		
40	234.0	42					
41	242.6	41					
234	243.2	42	9	81	64		
42	245.7	41					
43	247.7	33	141	36	172		
44	248.1	55					
45	252.3	55					
46	261.1	76					
47	265.2	77					
48	273.3	33					
49	274.4	55					
50	286.5	55					
51	294.4	43					
52	305.4	53					
53	307.0	56	105	43	122		
54	309.5	41					
55	312.5	31	297	80	8		
56	316.3	44					
57	317.2	48					
57×	318.6	51	267	51	2		
236	321.7	51	109±	42	124	59	15
57××	302.1	26					
58	330.5	49					
60×	332.9	47	240	39	341		
59	337.5	42					
60	341.6	33	276	68	354		
62	343.4	48					
61	343.5	37					
63	352.3	49	264	51	357		
64	357.9	62					
63×	358.4	33	243	48	331		
65	364.7	42					
67	367.0	39					
65×	369.1	60					
66	370.2	50	99	47	120		

RADINTER MODEL INFORMATION

(20, 100 and 250 MHz Dipole Antennas and Directional antenna)

Site: Forsmark

Borehole name: KFM08A

Nominal velocity (m/μs): 128.0

Name	Intersection depth	Intersection angle	Object direction	Dip 1	Strike 1	Dip 2	Strike 2
237	375.9	54	111	39	120		
238	380.8	52	261	47	2		
222	381.3	52					
69	382.8	54					
68	389.0	37					
70	389.8	53					
71	392.8	66					
221	394.9	40					
71×	395.7	47	93	54	121		
72	400.2	40	87	58	119		
73	403.5	38					
74	410.1	43	90±	58	123	58	358
75	413.2	48					
74×	415.8	29					
76	424.6	65					
79	430.8	35					
77	431.4	62					
74××	432.8	22					
78	434.4	49					
80	434.3	60	303±	59	31	31	115
81	438.0	60					
83	440.3	44					
239	446.9	42	300	72	19		
82	450.6	57					
84	458.6	68	198±	18	39	62	72
85	465.0	54					
86	466.7	43					
89	468.7	65	105	45	124		
90	468.7	27					
88	471.5	73					
87	472.0	47					
245	478.8	52					
91	480.2	25					
92	481.0	74					
93	483.6	53					
223	484.6	27					
94	485.5	45					
95	486.5	48					
225	487.2	53					
96	495.6	64	108±	39	107	52	32
224	497.2	44					

RADINTER MODEL INFORMATION							
(20, 100 and 250 MHz Dipole Antennas and Directional antenna)							
Site:	**Forsmark**						
Borehole name:	**KFM08A**						
Nominal velocity (m/μs):	**128.0**						
Name	**Intersection depth**	**Intersection angle**	**Object direction**	**Dip 1**	**Strike 1**	**Dip 2**	**Strike 2**
97	498.1	65					
99	499.3	68					
98	501.1	65					
100	506.6	59					
101	513.3	62					
103	516.7	54					
102	518.8	74					
104×	529.6	53					
104	530.2	58	90	50	111		
240	535.1	51	63	65	102		
228	535.2	48					
105	543.1	61					
107	544.1	69	96	42	98		
106	544.4	55					
108	546.0	69					
109	550.5	65					
110	552.2	58					
229	552.7	44					
111	554.6	63					
112	557.6	57					
113	563.1	74	315±	54	55	32	92
114	564.9	90					
241	566.1	50	267	53	10		
115	574.1	59					
116	577.9	61					
117	580.0	67					
118	582.0	77					
119	590.2	61					
124	592.6	77					
120	597.7	67					
121	599.8	61	87	53	111		
123	606.4	61					
122	609.0	60					
125	612.4	64	105	42	109		
126	613.0	72					
127	616.3	73	93	44	92		
128	618.1	43					
227	618.7	41					
129	623.9	90					
131	628.0	67					
130	633.3	58					

RADINTER MODEL INFORMATION

(20, 100 and 250 MHz Dipole Antennas and Directional antenna)

Site: Forsmark

Borehole name: KFM08A

Nominal velocity (m/µs): 128.0

Name	Intersection depth	Intersection angle	Object direction	Dip 1	Strike 1	Dip 2	Strike 2
132	638.7	70	102	42	101		
246	643.1	57					
133	649.1	68					
134	652.3	69					
231	654.7	42					
135	654.9	85					
136	659.8	68					
137	663.3	73					
138	669.4	56					
139	673.0	75					
140	675.4	69	177	20	72		
141	676.7	44					
142	682.5	58					
143	686.1	47	225	30	1		
144	687.1	56					
145	695.6	82					
146	698.3	80					
147	700.3	71					
226	703.7	61					
149	709.9	62					
150	711.7	68					
148	715.6	61					
151	725.8	46					
152	730.9	67	99	45	102		
153	732.5	86					
154	734.2	79					
155	737.0	71					
162	738.1	90					
242	743.7	79	102±	45	89	49	60
156	743.9	72					
230	745.1	64					
157	746.4	72					
158	753.3	90					
160	767.3	80	258±	45	64	49	85
159	768.5	90					
161	775.1	65					
163	785.7	90					
164	790.5	65					
165	793.0	87					
166	793.8	84					
167	801.2	88					

RADINTER MODEL INFORMATION							
(20, 100 and 250 MHz Dipole Antennas and Directional antenna)							
Site:	**Forsmark**						
Borehole name:	**KFM08A**						
Nominal velocity (m/μs):	**128.0**						
Name	**Intersection depth**	**Intersection angle**	**Object direction**	**Dip 1**	**Strike 1**	**Dip 2**	**Strike 2**
243	807.3	15	84	84	149		
168	807.4	86					
244	810.4	51	102	50	127		
169	812.5	69	204±	29	59	67	86
172	823.4	74					
170	826.8	90					
171	834.8	90					
173	832.2	90					
174	838.9	84					
175	852.0	71					
176	852.6	70					
177	863.2	90					
178	866.5	90					
179	877.6	69					
180	881.7	76					
181	884.1	67					
182	888.0	63					
183	889.7	68					
190	897.8	71					
191	903.3	71					
192	904.7	68					
193	907.0	83					
194	916.3	63					
195	920.2	71					
196	921.9	64					
197	923.1	63					
198	925.9	89					
199	936.3	73					
200	942.8	73					
201	945.2	75					
202	950.5	75					
203	952.8	72					
204	955.6	75					
205	963.7	56					
213	967.8	55					
214	969.7	59					
206	972.0	57					
207	975.5	90					
212	982.0	85					
210	983.4	73					
211	986.7	71					

RADINTER MODEL INFORMATION							
(20, 100 and 250 MHz Dipole Antennas and Directional antenna)							
Site:	Forsmark						
Borehole name:	KFM08A						
Nominal velocity (m/μs):	128.0						
Name	Intersection depth	Intersection angle	Object direction	Dip 1	Strike 1	Dip 2	Strike 2
208	996.4	64					
209	999.9	62					
215		0	270	90	327		
218		1					
219		5					
233		0	273	88	150		

Table 5-3. Borehole length intervals in KFM08A with decreased amplitude for the 250 MHz antenna.

Depth (m)	
190	555
195–200	580–585
245	610–620
255–260	685–690
275	725
310	730
340–345	790
365	800–805
410	810
430	820
460	880
475–485	915–920
490–500	965–975
530	985
545	

5.2 BIPS logging

The BIPS pictures are presented in Appendix 2.

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 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 one year of logging is that the marks on the logging cable is very good and differs very little compared with the results from core-drilled boreholes.

The BIPS images in the appendix are adjusted for the tension of the cable and error of the depth readings from the measuring wheel. The adjusted depth is showed in red colour and the recording depth have black colour in the printouts.

In Figure 5-3 the marks at a depth of 700 m borehole length (from six individual measurements) on the logging cable is visible with different colours. The maximum difference is seen to be 55 cm in-between the red and green mark. The difference is what we believe due to the different dip angles of the boreholes that change the stretch factor on the logging cable.

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

The BIPS images show some influences by the discolouring effect from the drilling. This effect is lesser in the shallower parts of the borehole. In general, the images are of reasonable quality. From 800 m down to the bottom, mud is covering the lower most part of the borehole wall, which limits the visibility.

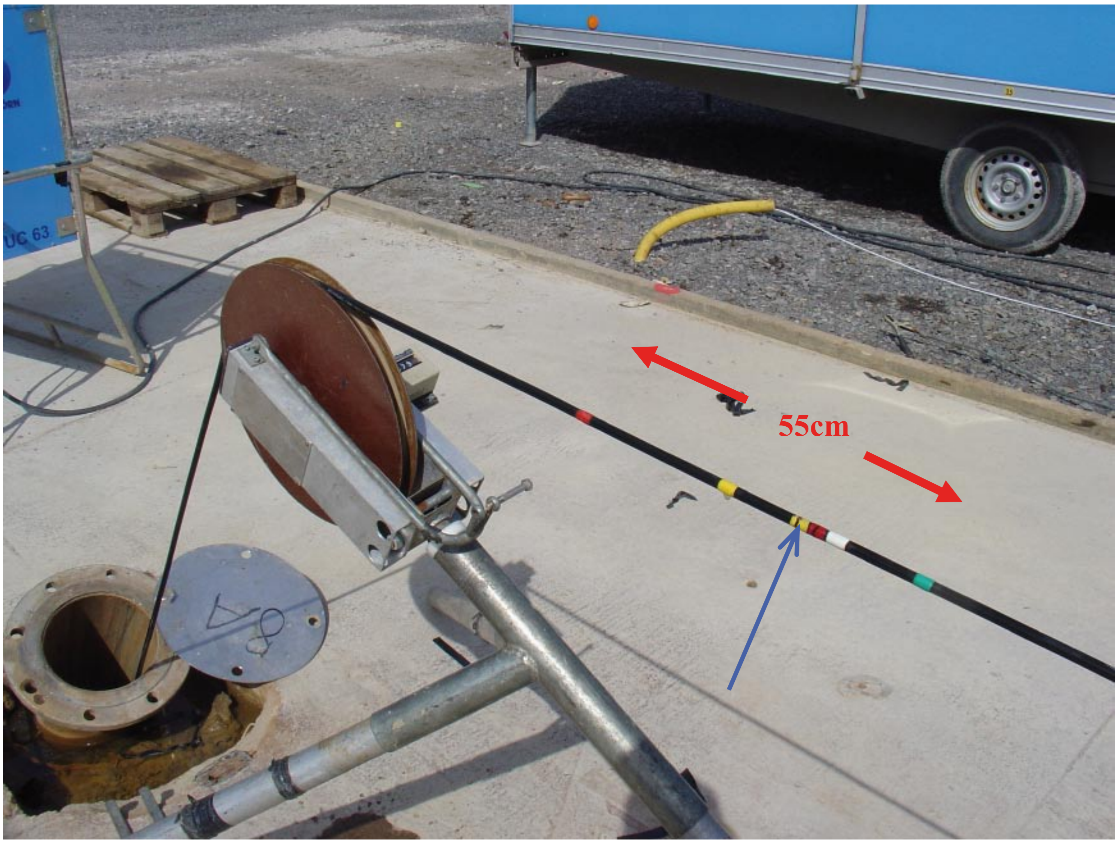
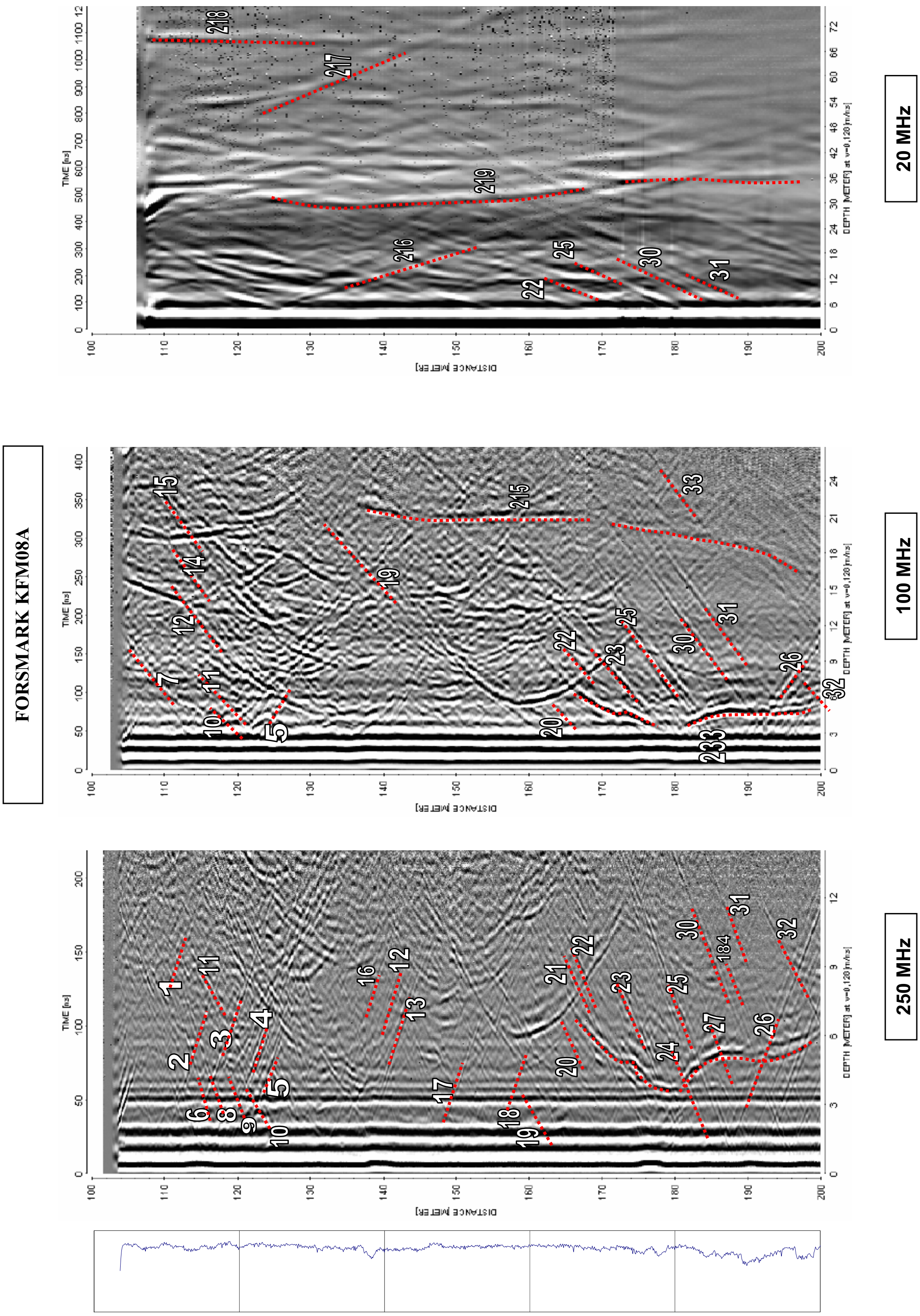


***Figure 5-3**. Marks at 700 m from six individual borehole loggings. The yellow/black tape indicated with a blue arrow was used for the actual measurements in KFM08A.*

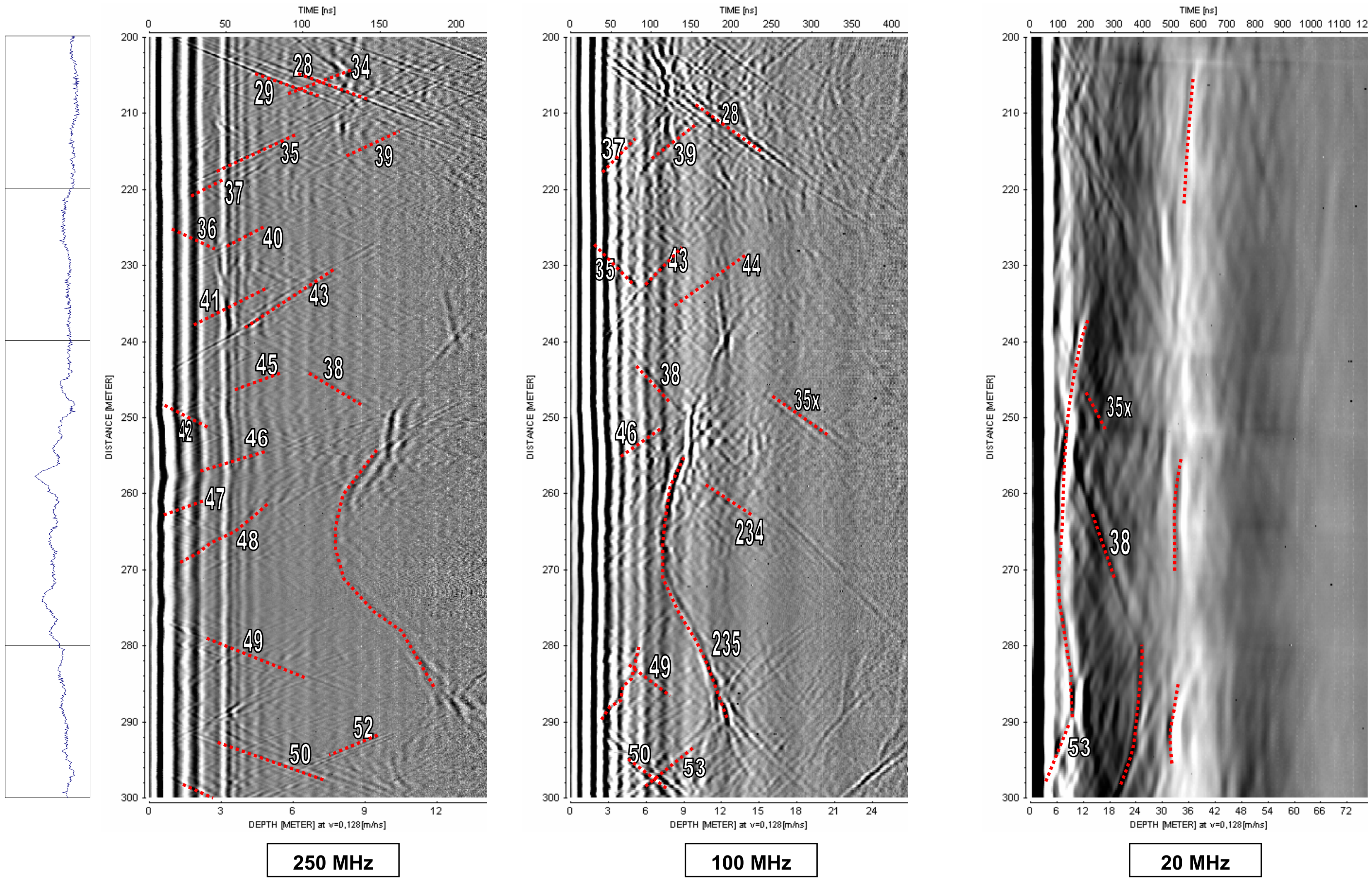
References

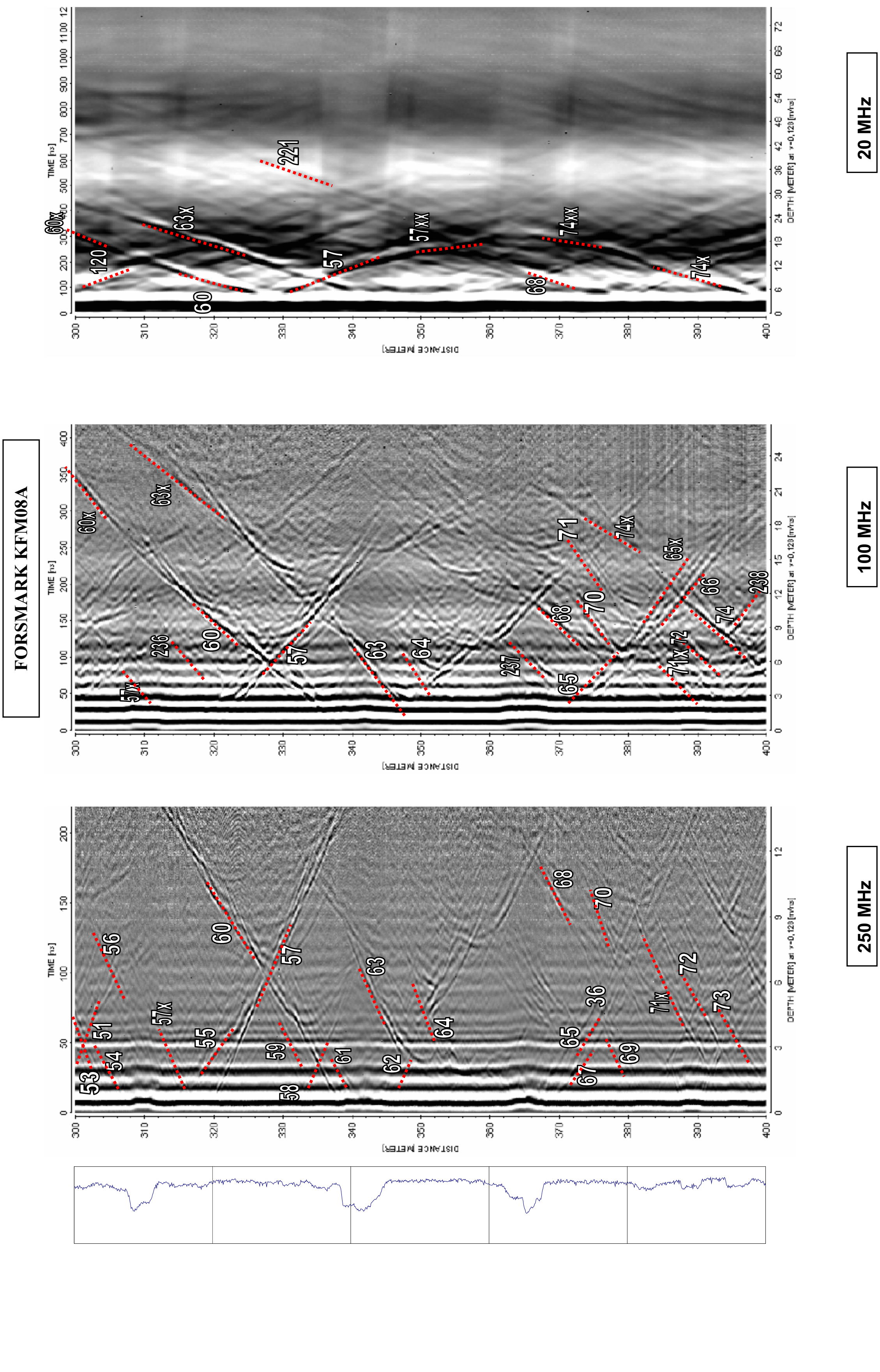
/1/ **Gustafsson C, Nilsson P, 2003.** Geophysical Radar and BIPS logging in borehole HFM01, HFM02, HFM03 and the percussion drilled part of KFM01A. SKB P-03-39. Svensk Kärnbränslehantering AB.

Radar logging in KFM08A, 100 to 990 m, dipole antennas 250, 100 and 20 MHz

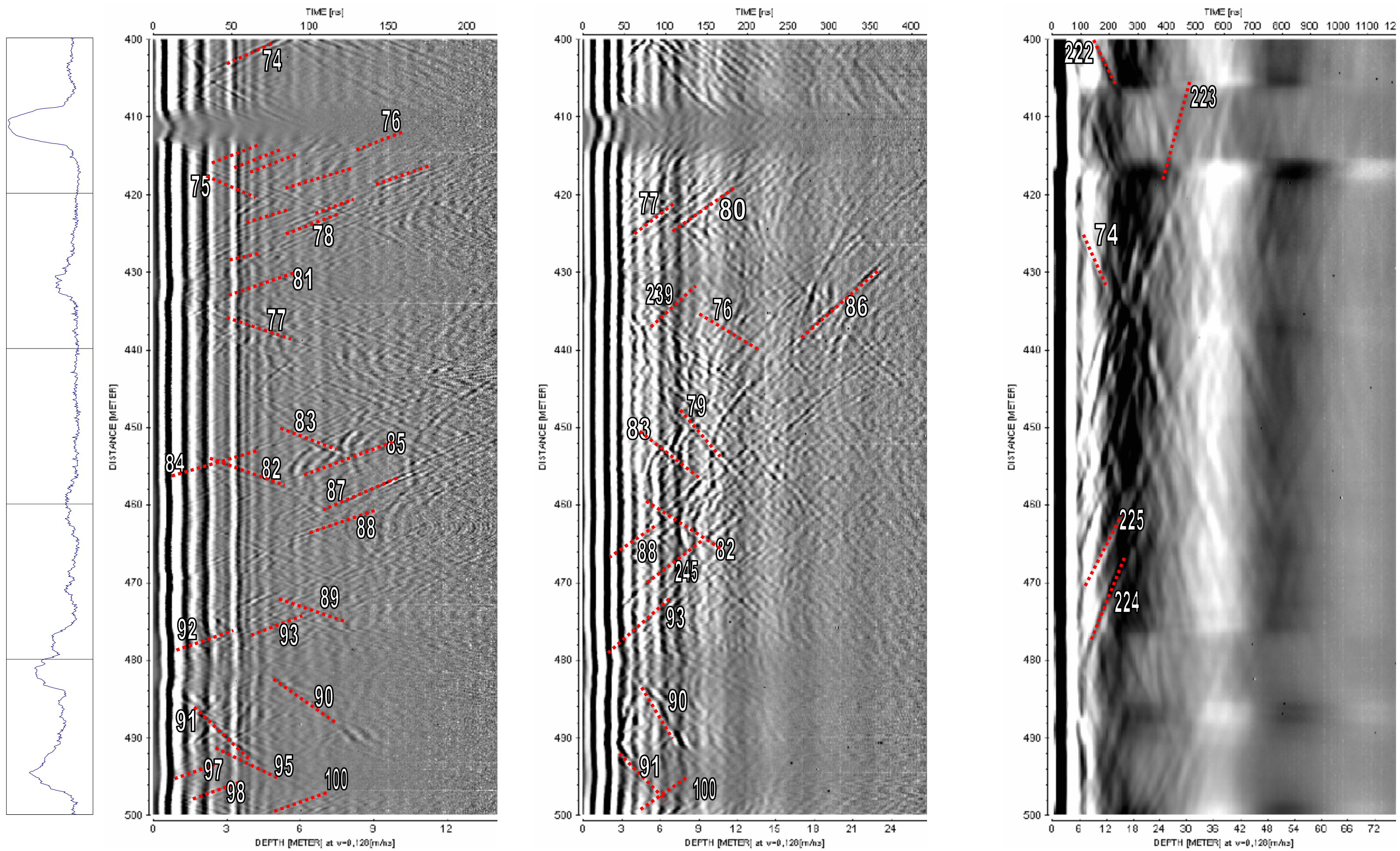


FORSMARK KFM08A




FORSMARK KFM08A
20 MHz
100 MHz
250 MHz

FORSMARK KFM08A

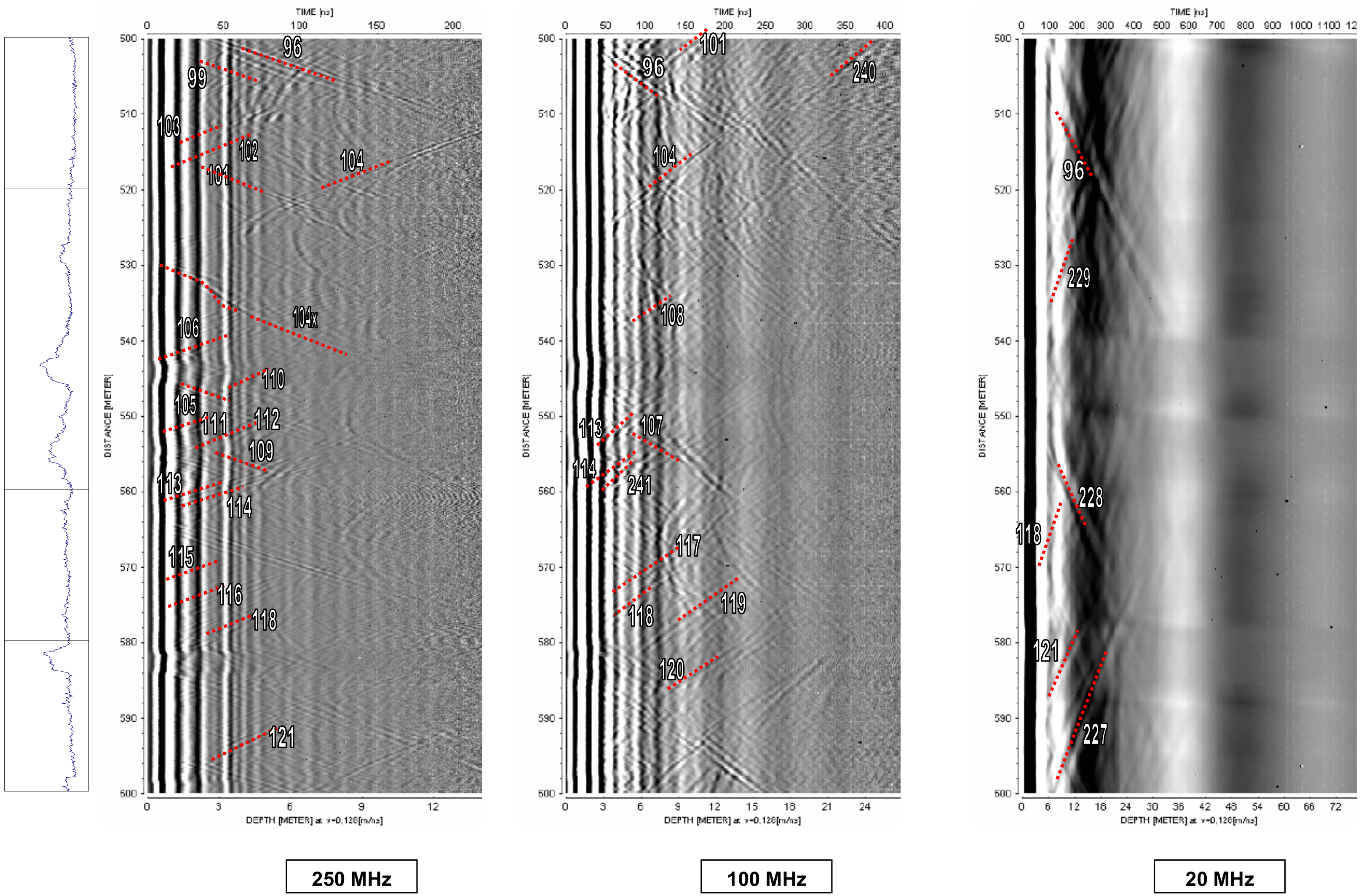


250 MHz

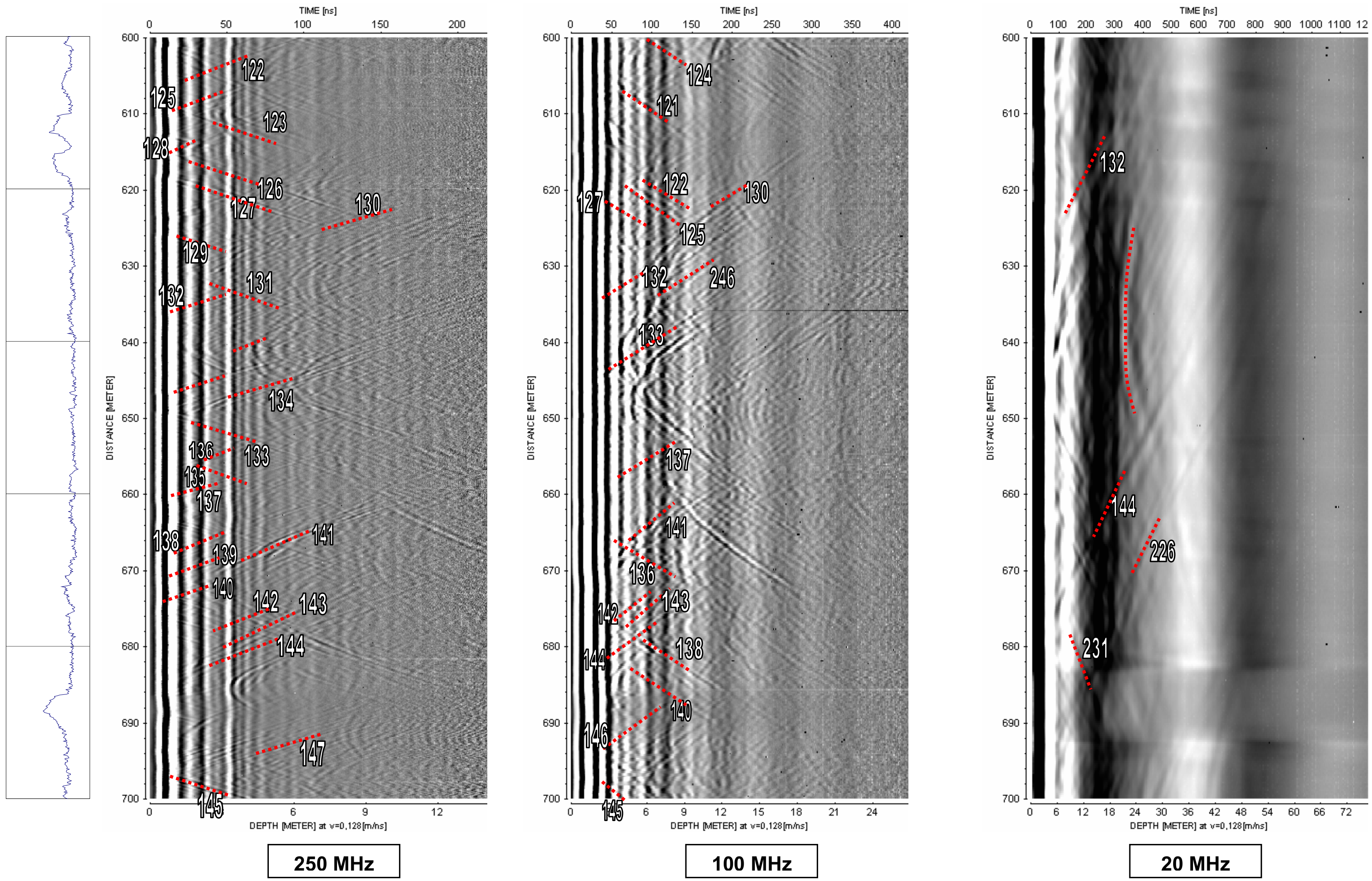
100 MHz

20 MHz

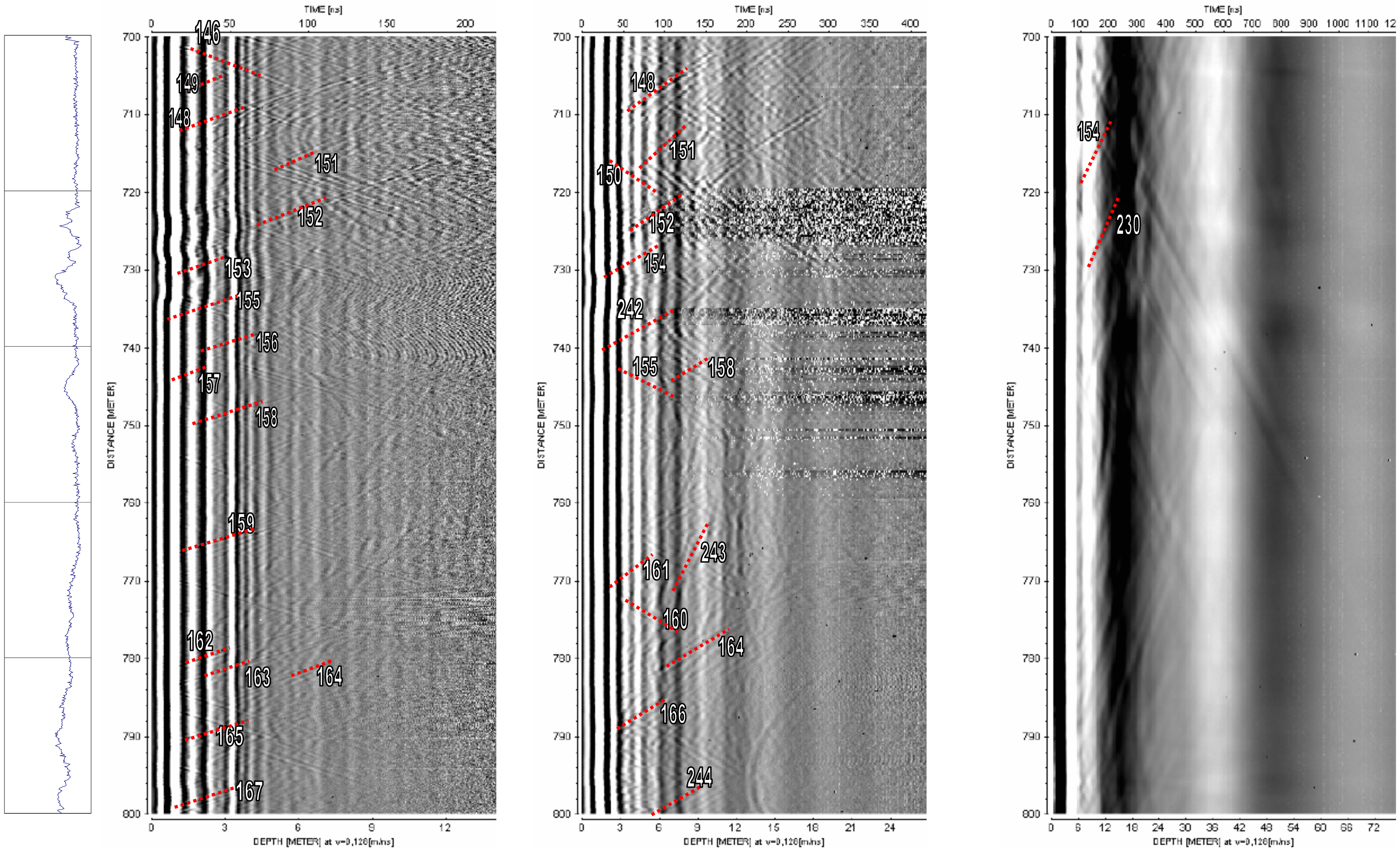
FORSMARK KFM08A



FORSMARK KFM08A



FORSMARK KFM08A

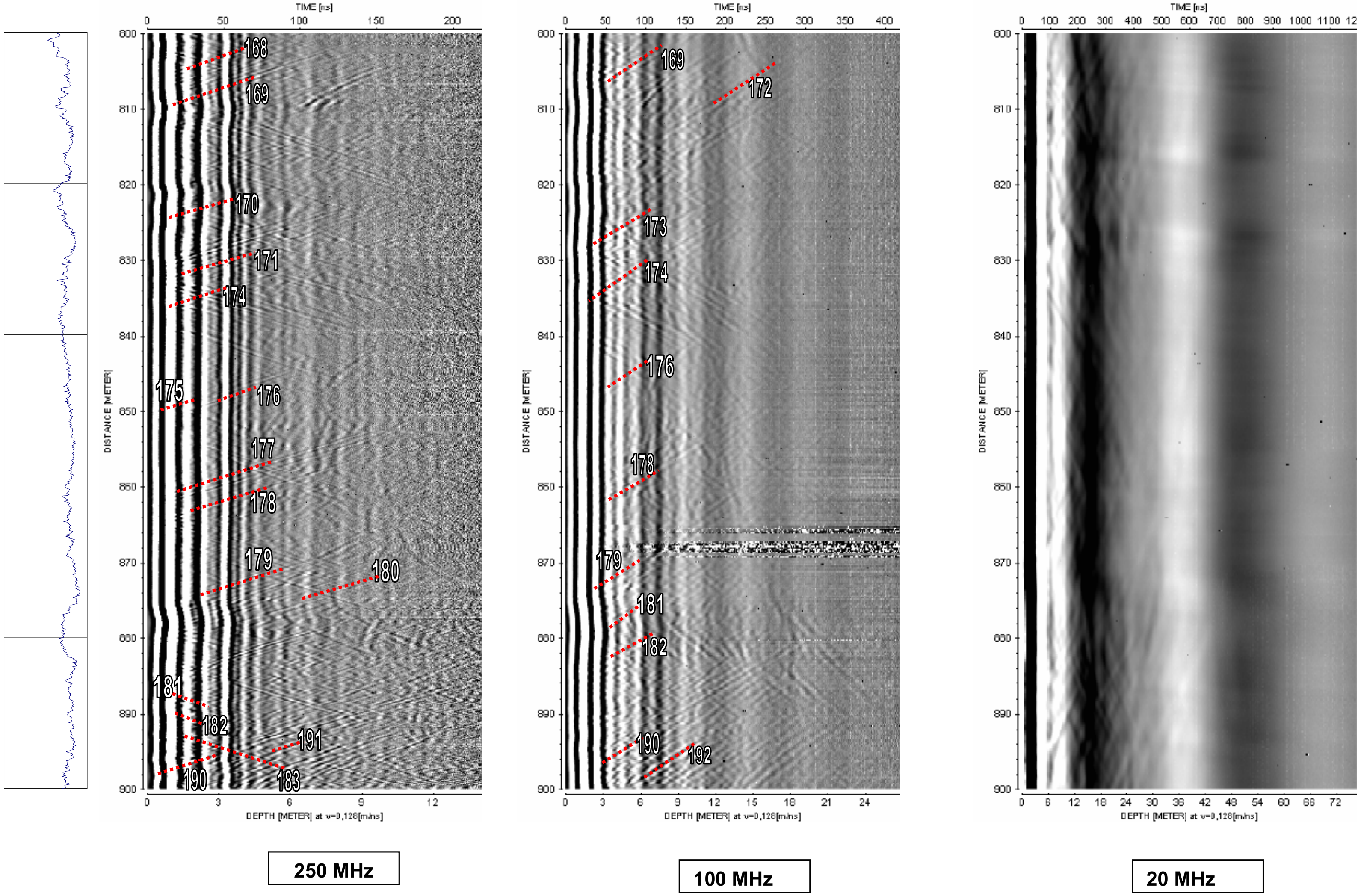


250 MHz

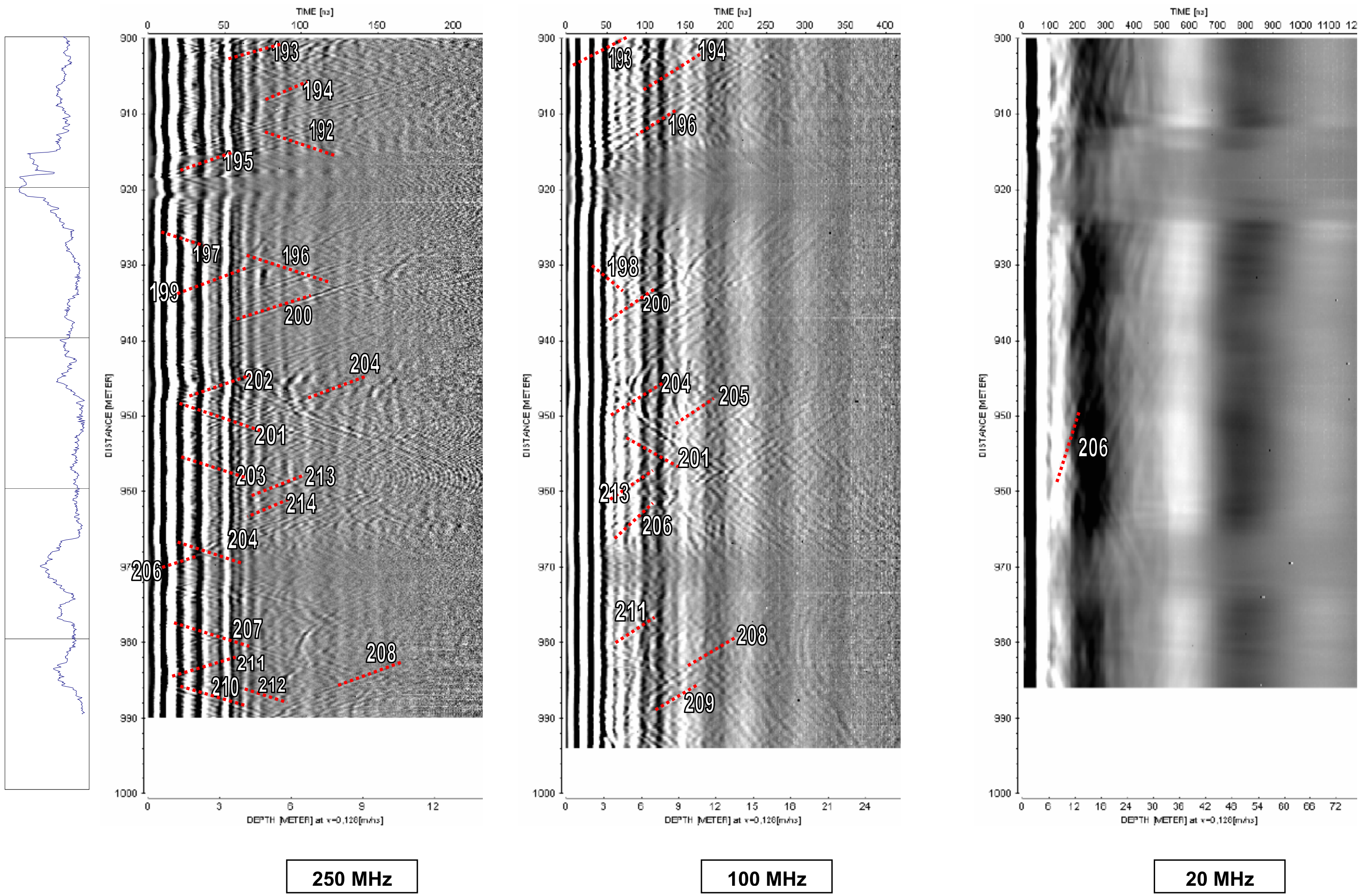
100 MHz

20 MHz

FORSMARK KFM08A



FORSMARK KFM08A



Appendix 2

BIPS logging in KFM08A, 102 to 980 m

Project name: Forsmark

Image file	: c:\work\r5399s~1\bips\kfm08a\102_500.bip
BDT file	: c:\work\r5399s~1\bips\kfm08a\102_500.bdt
Locality	: FORSMARK
Bore hole number	: KFM08A
Date	: 05/05/09
Time	: 14:33:00
Depth range	: 102.000 - 980.000 m
Azimuth	: 319
Inclination	: -60
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	: 20
Color	: +0 +0 +0

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 100.000 - 120.000 m

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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 120.000 - 140.000 m

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

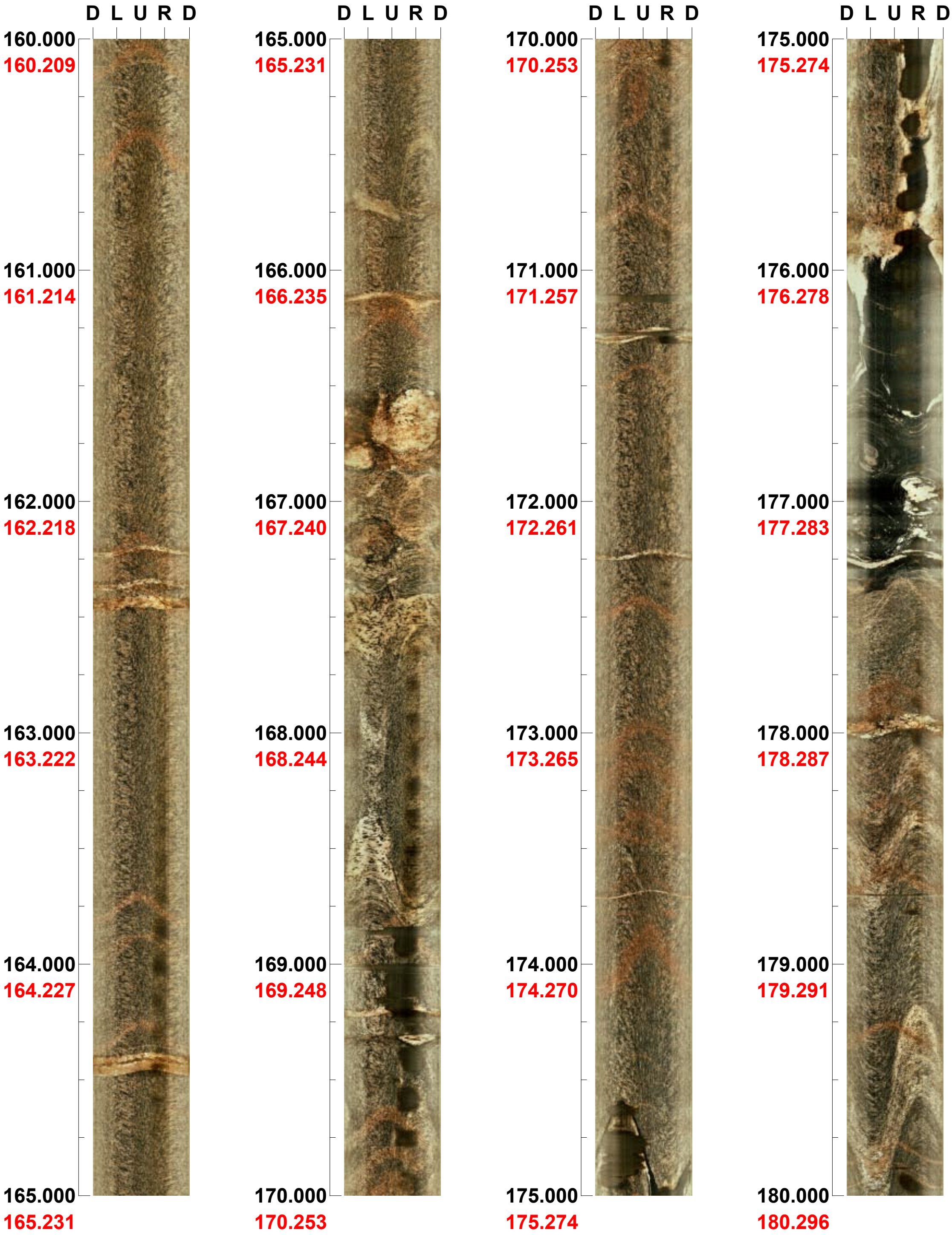
Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 140.000 - 160.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A Azimuth: 319 Inclination: -60

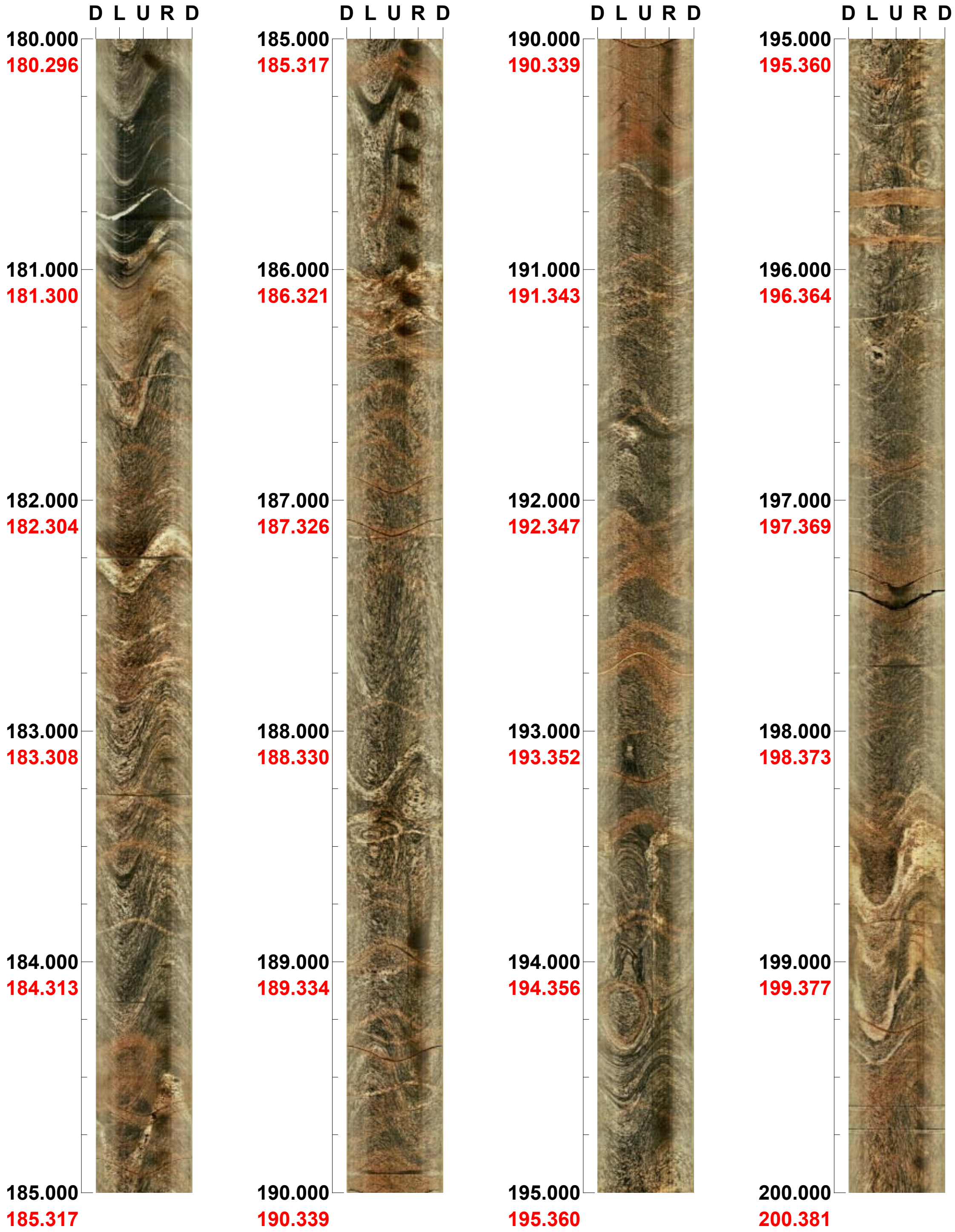
Depth range: 160.000 - 180.000 m



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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 180.000 - 200.000 m



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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 200.000 - 220.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 220.000 - 240.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 240.000 - 260.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 260.000 - 280.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 280.000 - 300.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 300.000 - 320.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 320.000 - 340.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 340.000 - 360.000 m

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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 360.000 - 380.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 380.000 - 400.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 400.000 - 420.000 m

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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 420.000 - 440.000 m

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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 440.000 - 460.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 460.000 - 480.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 480.000 - 499.998 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 0** **Inclination: -90**

Depth range: 500.000 - 520.000 m

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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 520.000 - 540.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 540.000 - 560.000 m

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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 560.000 - 580.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 580.000 - 600.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 600.000 - 620.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 620.000 - 640.000 m

D L U R D

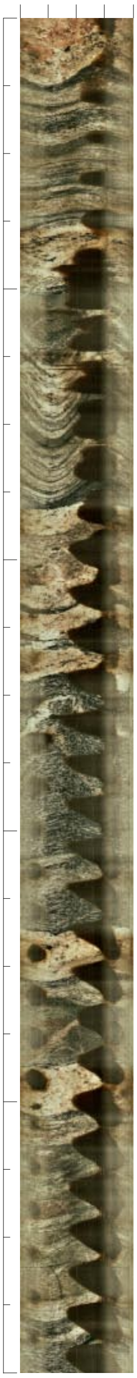
620.000
621.809
621.000
622.812
622.000
623.816
623.000
624.819
624.000
625.823
625.000
626.827

D L U R D

625.000
626.827
626.000
627.830
627.000
628.834
628.000
629.837
629.000
630.841
630.000
631.845

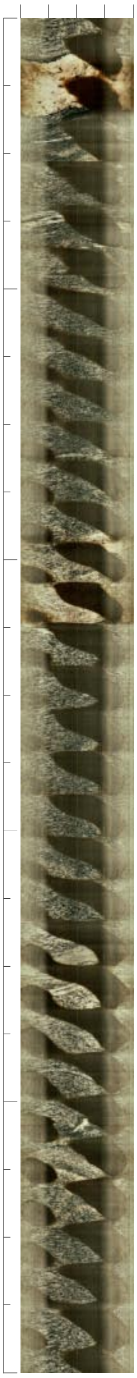
D L U R D

630.000
631.845
631.000
632.848
632.000
633.852
633.000
634.855
634.000
635.859
635.000
636.863



D L U R D

635.000
636.863
636.000
637.866
637.000
638.870
638.000
639.874
639.000
640.877
640.000
641.881



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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 640.000 - 660.000 m

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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 660.000 - 680.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 680.000 - 700.000 m

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

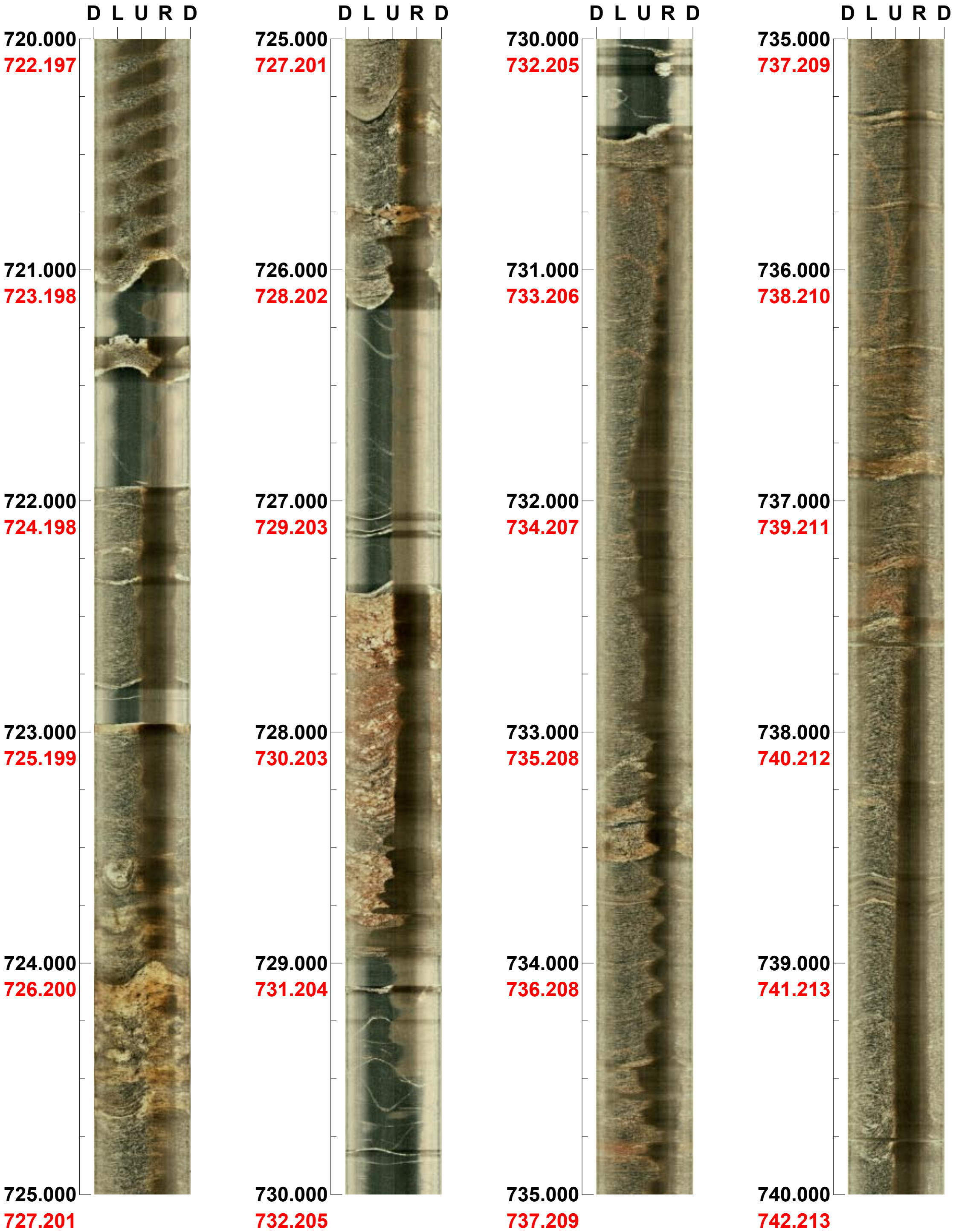
Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 700.000 - 720.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A Azimuth: 319 Inclination: -60

Depth range: 720.000 - 740.000 m



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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 740.000 - 760.000 m

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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 760.000 - 780.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 780.000 - 800.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 800.000 - 820.000 m

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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 820.000 - 840.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 840.000 - 860.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 860.000 - 880.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A

Azimuth: 319 Inclination: -60

Depth range: 880.000 - 900.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A Azimuth: 319 Inclination: -60

Depth range: 900.000 - 920.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A Azimuth: 319 Inclination: -60

Depth range: 920.000 - 940.000 m

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

Project name: Forsmark
Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

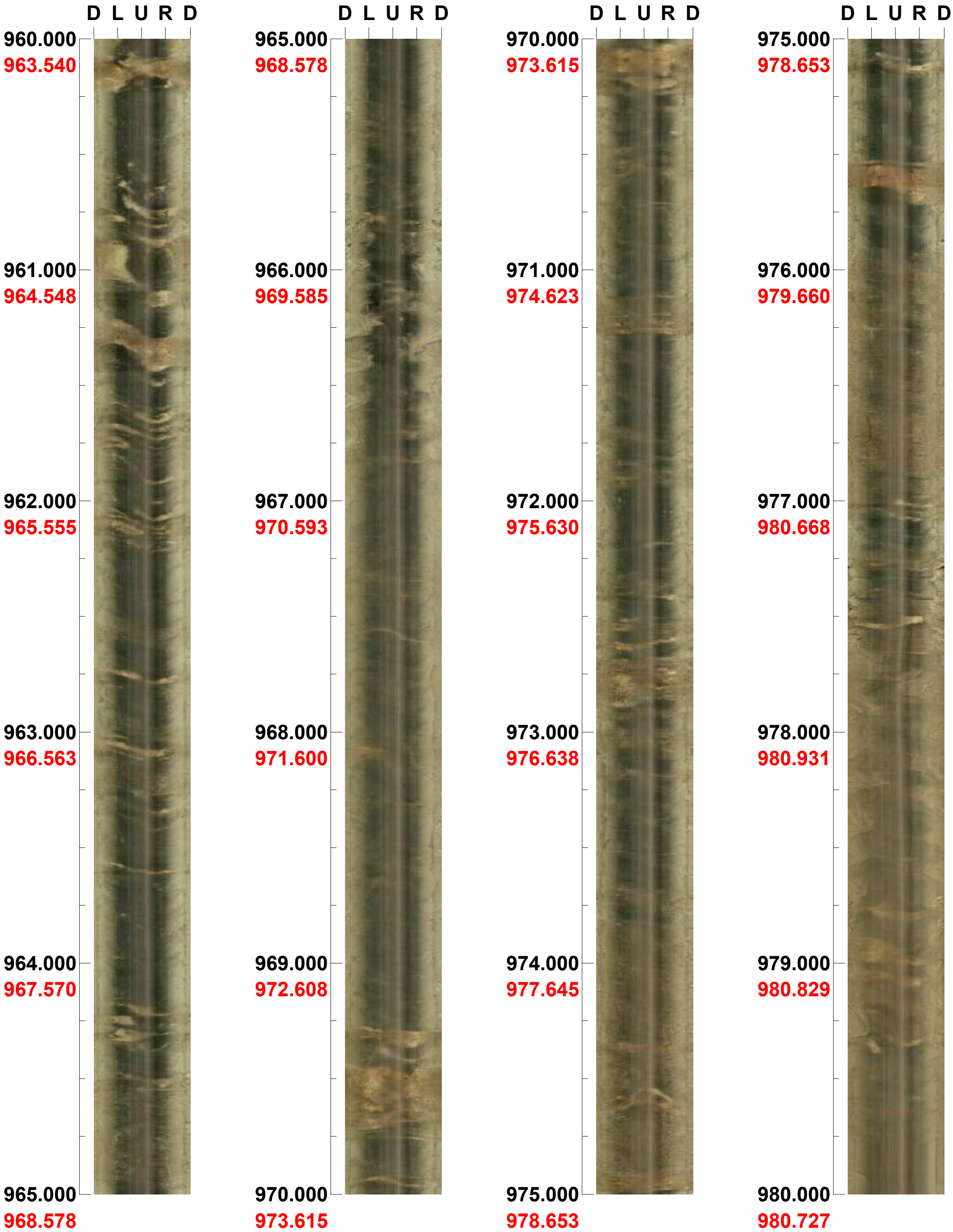
Depth range: 940.000 - 960.000 m

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

Project name: Forsmark

Bore hole No.: KFM08A **Azimuth: 319** **Inclination: -60**

Depth range: 960.000 - 980.000 m



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