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Forsmark site investigation

RAMAC and BIPS logging in borehole KFM01A

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April 2003

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Keywords: BIPS, RAMAC, radar, TV, geophysical logging

This report concerns a study which was conducted in part 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.

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Contents

1	**Introduction**	5
2	**Objective and scope**	7
3	**Equipment**	9
3.1	RAMAC	9
3.2	TV-Camera, BIPS	10
4	**Execution**	11
4.1	Data acquisition	11
4.2	Analyses and Interpretation	13
5	**Results and data deliery**	15
5.1	RAMAC logging	15
5.2	BIPS logging	18
6	**References**	19

Appendix 1 – Radar logging of KFM01A
Dipole antennas 250, 100 and 20 MHz 21

1 Introduction

This document reports data gained during borehole logging, which is one of the activities performed within the site investigation at Forsmark. The logging operations presented here include borehole radar (RAMAC) and TV-logging (BIPS) and were carried out in the core drilled part of the 1001.5 m long telescopic borehole KFM01A (see Figure 1-1), from 100 m to approximately 990 m. The diameter of the core drilled part is c. 76 mm. Borehole section 0–100 m, which is percussion drilled and today supplied with a casing of 200 mm inside diameter, was previously planned to be RAMAC- and BIPS-logged within the frame of another activity. However, due to an instability in the borehole, only section 0–50 m was possible to accomplish /1/. Hence, RAMAC- and BIPS-logging has been performed within the intervals 0–50 m and 100–990 m in borehole KFM01A.

The measurements were conducted by Malå Geoscience AB/RAYCON in December 2002. The work was carried out according to activity plan AP PF 400-02-44 (SKB internal controlling document).

The investigation techniques comprised:

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

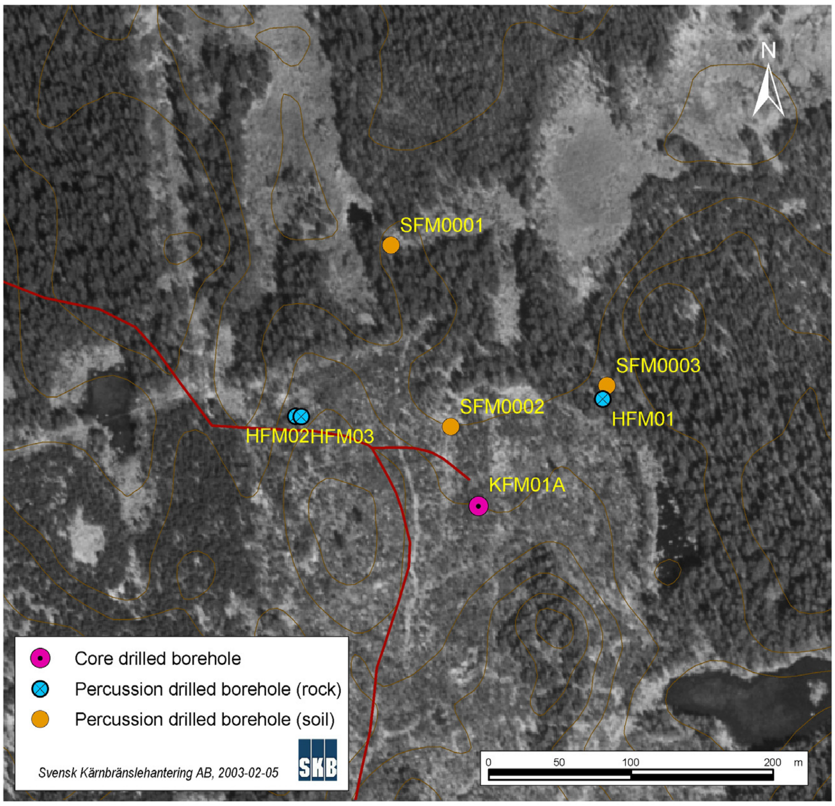


Figure 1-1. Overview of drillsite No. 1 in the Forsmark area.

2 Objective and scope

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

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

3 Equipment

3.1 RAMAC

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

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

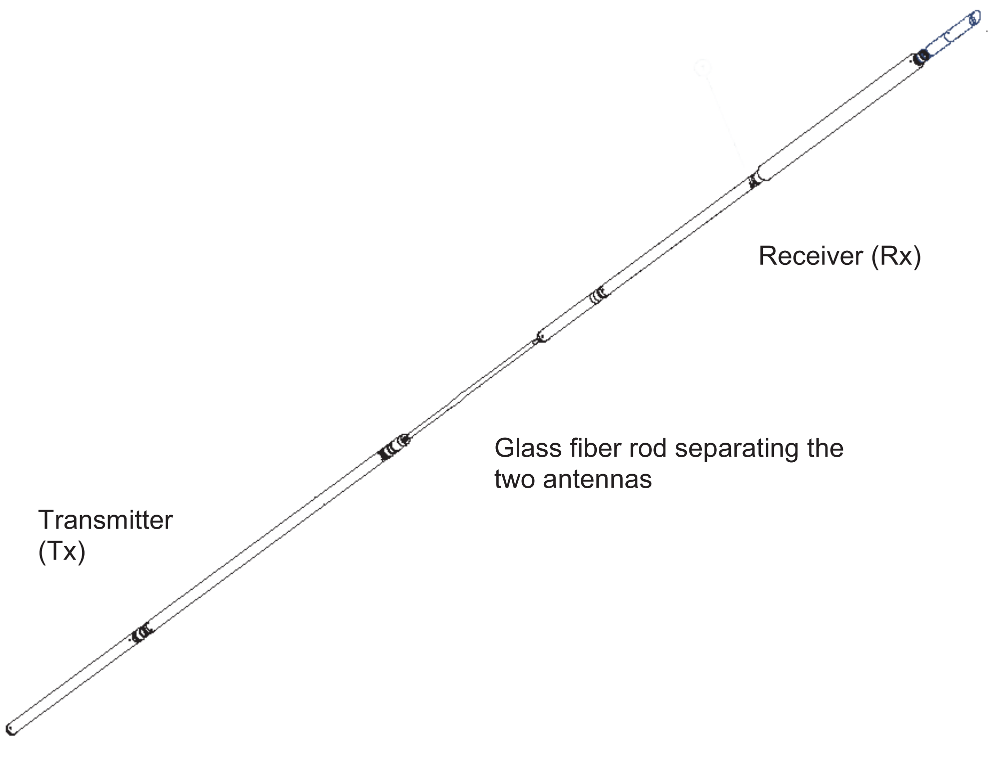


Figure 3-1. *Example of a borehole antenna.*

3.2 TV-Camera, BIPS

The BIPS 1500 system used is owned by SKB and described in the method description ”Metodbeskrivning för TV-loggning med BIPS” (SKB MD 222.006, Version 1.0). The BIPS method for borehole logging produces a digital scan of the borehole wall. In principle, a standard CCD video camera is installed in the probe in front of a conical mirror (see Figure 3-2). An acrylic window covers the mirror part, and the borehole image is reflected through the window and displayed on the cone, from where it is recorded. During the measuring operation, pixel circles are scanned 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).

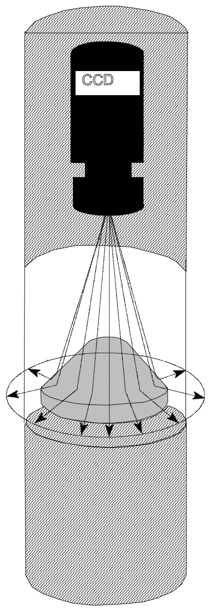


Figure 3-2. *The BIP-system. Illustration of the conical mirror scanning.*

4 Execution

4.1 Data acquisition

RAMAC

For the borehole radar measurements, both dipole and directional antennas were engaged. The dipole antennas are operated with central frequencies of 20, 100, and 250 MHz, respectively, whereas the directional antenna has a central frequency of 60 MHz.

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

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

Information on the system settings for the different antennas used in the investigation of KFM01A is presented in Table 4-1 below.

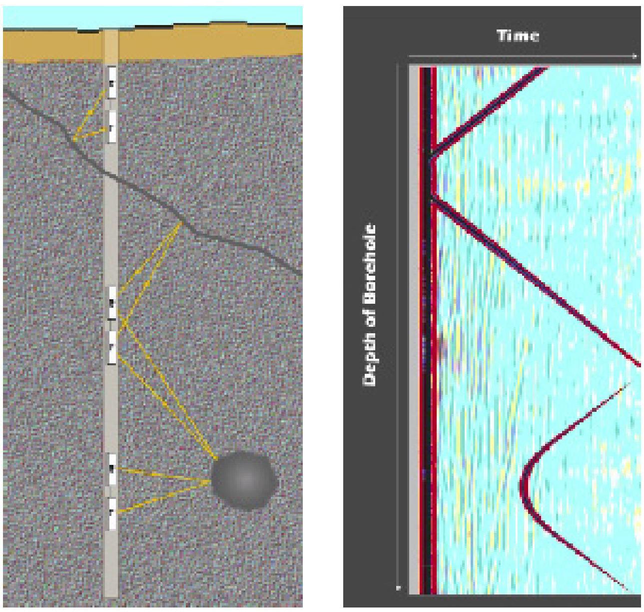


Figure 4-1. *The principle of a radar borehole reflection survey (left) and a resulting radargram (right).*

Table 4-1. Radar logging information from KFM01A.

Site:	**Forsmark**	**Logging company:**	**RAYCON**		
BH:	**KFM01A**	**Equipment:**	**SKB RAMAC**		
Type:	**Directional / Dipole**	**Manufacturer:**	**MALÅ GeoScience**		
Operators:	**CG / JA**	**Antenna**			
		Directional (60 MHz)	**250 MHz**	**100 MHz**	**20 MHz**
	Logging date:	02-12-12	02-12-12	02-12-12	02-12-12
	Reference:	T.O.C.	T.O.C.	T.O.C.	T.O.C.
	Sampling frequency (MHz):	665	2588	951	247
	Number of samples:	512	575	518	512
	Number of stacks:	64	32	32	32
	Signal position:	373.987	-0.319	-0.358	-1.361
	Logging from (m):	107.4	111.35	112.15	116.3
	Logging to (m):	990.0	995	991.01	989.86
	Trace interval (m):	0.5	0.25	0.2	0.1
	Antenna separation (m):	5.73	1.9	2.9	10.05

BIPS

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

During the measurement, a pixel circle with a resolution of 360 pixels/circle was stored at every 1 millimetre on a MO-disc in the surface unit. The maximum speed during data collection was 1.5 metre/minute.

A gravity sensor measured the orientation of the image.

Depth measurements

The depth recording for the RAMAC and BIPS systems is taken care of by a measuring wheel mounted on the cable winch. Whenever reference marks in the borehole are visible on the image displayed by the ground unit during the BIPS logging, the logging cable is marked with a piece of red scotch tape. These marks are then used for controlling the depth registration during the RAMAC measurements.

In Figure 4-2, the divergence between the individual measurements and the difference compared to the reference marks is plotted. The difference is increasing towards depth due to stretching of the measurement cable. The length recordings of the radar measurements were adjusted before the final data delivery.

The difference between the dipole antennas and the directional antenna is due to the fact that different systems are used for calibration of the depth recordings. In the directional antenna system the depth recording is implemented in the automatic winch control, whereas for the dipole antennas the measurement software controls the depth.

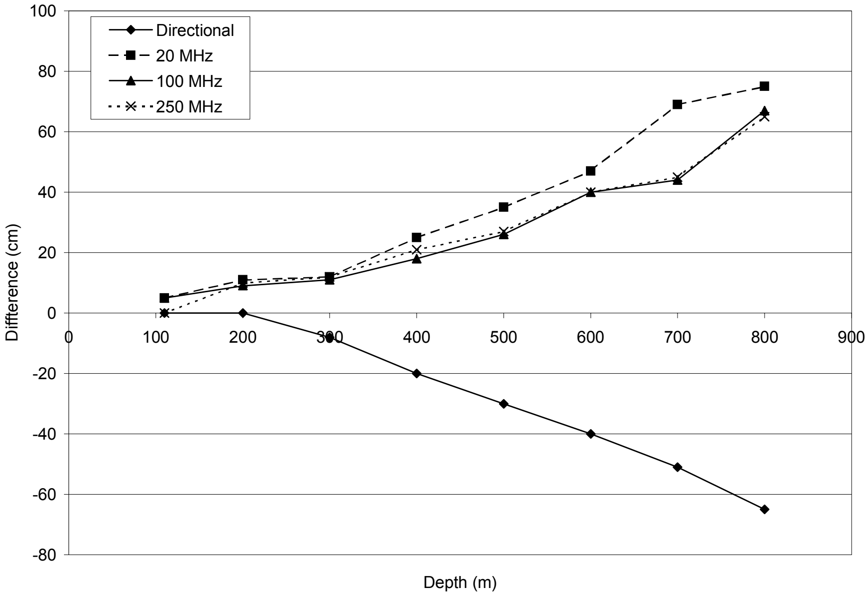


Figure 4-2. *Illustration of the divergence in depth measurements for the different radar antennas used and the difference compared to the borehole reference marks. The depths of the dipole antennas are larger than the depth of the borehole reference marks, whereas the depth of the directional antenna is less.*

4.2 Analyses and Interpretation

Radar

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

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

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

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

There are several ways to determine the radar wave propagation velocity. Each of them has its advantages and its disadvantages. In this project, the velocity determination was performed by keeping the transmitter fixed in a borehole at drillsite No. 1 (the percussion drilled borehole HFM03) while moving the receiver downwards in the borehole. The result is plotted in Figure 4-3. The calculation indicates a propagation velocity of 128 m/micro seconds. The velocity measurement was performed with the 100 MHz antenna /1/.

The visualization of data in Appendix 1 is made with REFLEX, a Windows based processing software for filtering and analysis of radar data. The processing steps are listed in Table 4-2.

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

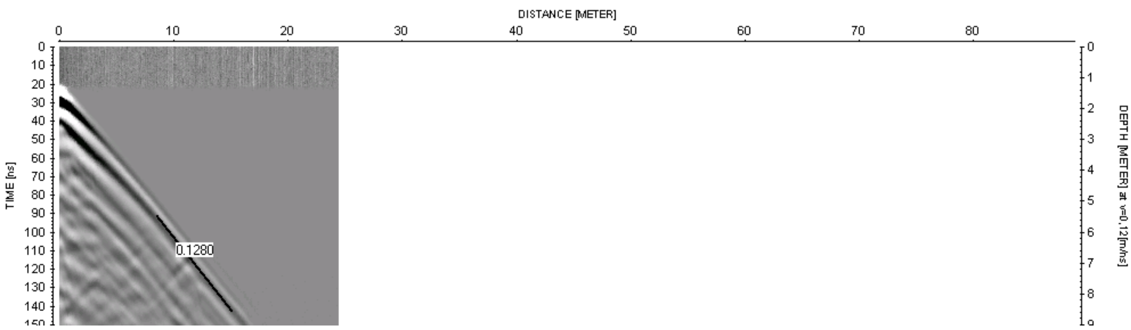


Figure 4-3. Results from velocity measurements in HFM03 /1/.

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

Site:	**Forsmark**	**Logging company:**	**RAYCON**		
BH:	**KFM01A**	**Equipment:**	**SKB RAMAC**		
Type:	**Directional / Dipole**	**Manufacturer:**	**MALÅ GeoScience**		
Interpret:	**JA**	**Antenna**			
		Directional (60 MHz)	**250 MHz**	**100 MHz**	**20 MHz**
	Processing:	DC removal	DC removal	DC removal	DC removal
		Move start time	Move start time	Move start time	Move start time
		FIR	Dynamic correction	Dynamic correction	Dynamic correction
		Time gain	Background removal	Background removal	Background removal
			Dewow	Gain	Bandpass
			Energy decay		Dewow
					Energy decay

BIPS

The visualization of data is made with BDPP, a Windows based processing software for filtering, presentation and analyzing of BIPS data. No fracture mapping based on the BIPS images was performed.

5 Results and data deliery

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

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

The SICADA reference to the BIPS and RAMAC logging activity in KFM01A is Field note Forsmark 89.

5.1 RAMAC logging

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

Results from measurements with the directional antenna are only presented in tabulated form, Table 5-2, with the identified planes and their orientation.

Only the major, clearly visible structures are interpreted in RadinterSKB. A number of minor structures were encountered as well, as indicated in Appendix 1. It should be observed that none of the reflections is interpreted as parallel to the borehole. Hence, all of them intersect the borehole or it's imagined extension.

The data quality, as seen in Appendix 1, is relatively satisfying. However, the measurements in part of the borehole suffer from deteriorated quality due to increased electrical conductive in the rock. A conductive environment entails attenuation of the radar waves, resulting in decreased penetration.

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

The identified structures intersecting the borehole are quite evenly distributed, see Table 5-1. Most structures are however encountered in borehole section 100–500 m.

Table 5-2 summarises the interpretation of radar data from KFM01A. Many structures can be identified in the data from more than one antenna frequency. When an object is detected by the directional antenna, the direction to the object (plane), as defined in Figure 5-1, is interpreted.

Table 5-1. Identified structures as a function of depth in KFM01A.

Depth (m)	No. of structures	Depth (m)	No. of structures
100 – 150	1	550 – 600	3
150 – 200	5	600 – 650	1
200 – 250	2	650 – 700	1
250 – 300	2	700 – 750	0
300 – 350	5	750 – 800	2
350 – 400	1	800 – 850	3
400 – 450	4	850 – 900	0
450 – 500	2	900 – 950	2
500 – 550	0	950 – 990	1

Table 5-2. Model information from dipole antennas 20, 100 and 250 MHz and the directional, 60 MHz antenna. For the definition of direction to object, see Figure 5-1

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas and Directional Antenna)
Site: **Forsmark**
Borehole name: **KFM01A**
Nominal velocity (m/μs): **128.00**

Object type	Name	Intersection depth	Intersection angle	Direction to object
PLANE	A	308.1	2	177
PLANE	B	162	21	225
PLANE	C	–255.4	6	
PLANE	D	186.1	12	228
PLANE	E	225.2	23	
PLANE	F	336.8	6	
PLANE	G	337.1	10	
PLANE	H	170.2	11	147
PLANE	I	263.7	10	159
PLANE	J	276.3	10	63
PLANE	K	304.8	12	
PLANE	L	370.8	8	
PLANE	M	403.6	10	330
PLANE	N	428.8	10	
PLANE	O	196	11	
PLANE	P	452.6	16	147
PLANE	Q	448.6	36	36
PLANE	R	469.2	17	
PLANE	S	490.1	25	
PLANE	T	571.4	11	
PLANE	U	648.3	4	
PLANE	V	557.7	12	
PLANE	Y	596.7	8	
PLANE	Z	759.5	27	90
PLANE	PP (Å in App. 1)	804.1	17	
PLANE	QQ (Ä in App. 1)	659.3	8	
PLANE	RR (Ö in App. 1)	780.1	14	
PLANE	AA	847.3	12	63

Object type	Name	Intersection depth	Intersection angle	Direction to object
PLANE	BB	831.2	33	
PLANE	CC	−731.9	1	
PLANE	DD	944.5	43	
PLANE	EE	984.2	49	75
PLANE	FF	304.5	19	
PLANE	GG	329.3	9	
PLANE	HH	201.2	12	264
PLANE	II	143.7	10	
PLANE	JJ	927.1	6	
PLANE	KK	141.5	29	
PLANE	LL	176.0	15	
PLANE	MM	218.2	18	
PLANE	NN	739.6	56	
PLANE	OO	859.5	27	

Names in table according to Appendix 1.

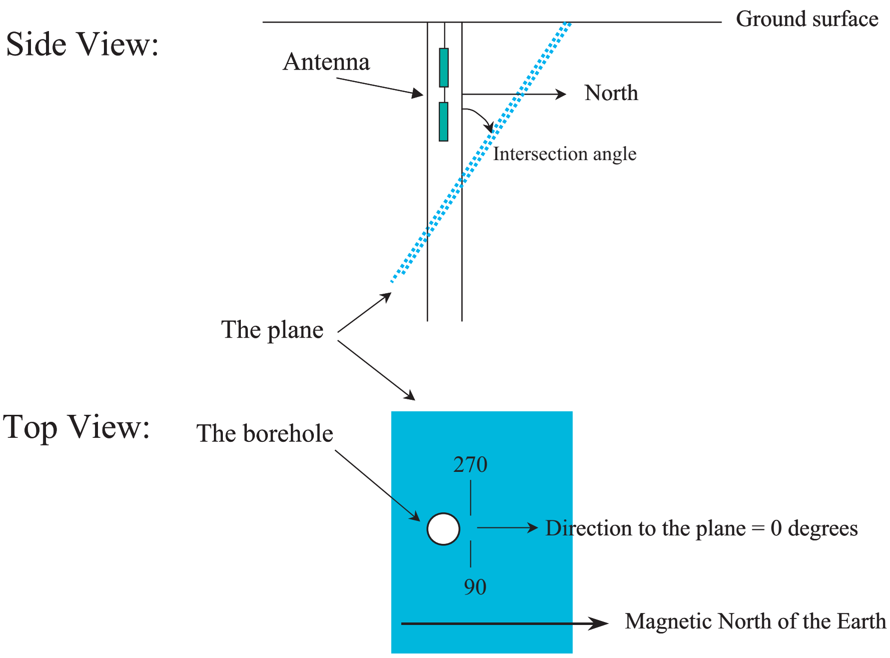


Figure 5-1. *Definition of direction to object as presented in Table 5-2.*

In Appendix 1, the amplitude of the first arrival is plotted against depth for the 250 MHz dipole antenna. The amplitude variation along the borehole indicates changes of the electric conductivity of the material. A decrease in this amplitude may indicate fracture zones, clay or rock volumes with increased water content. An amplitude decrease is observed for the following sections in KFM01A. 120–130, 140–150, 170–180, 215–225, 390–400, 650–670, 730–740, 770–775, and 855–860. These sections coincide, at least partly, with sections where the highest number of structures has been identified, with a concentration to the upper part (100–500 m) of the borehole.

5.2 BIPS logging

To get the best possible depth accuracy, the BIPS images were adjusted to the reference marks along the borehole. However, below 650 m, the reference marks are missing, due to dis-functioning of the marker tool.

In order to control the quality of the system, calibration measurements were performed in a test pipe before and after logging of the borehole. The resulting images displayed no difference regarding colours and focus of the images. Results from the test loggings were included in the delivery of raw data.

The BIPS images from borehole KFM01A are impaired by some quality problems, which, however, are system independent. Instead, the problems are related to a drilling induced discolouring of parts of the borehole wall, see example in Figure 5-2. The water quality, which is another crucial factor for achieving a satisfactory quality of the BIPS images, turned out to be fairly good along the borehole during logging.

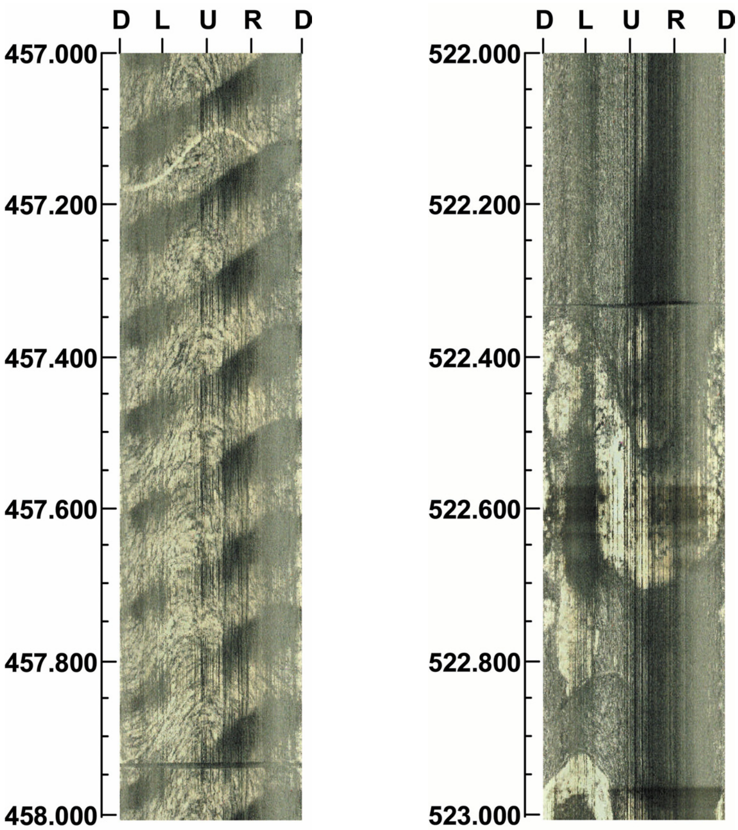


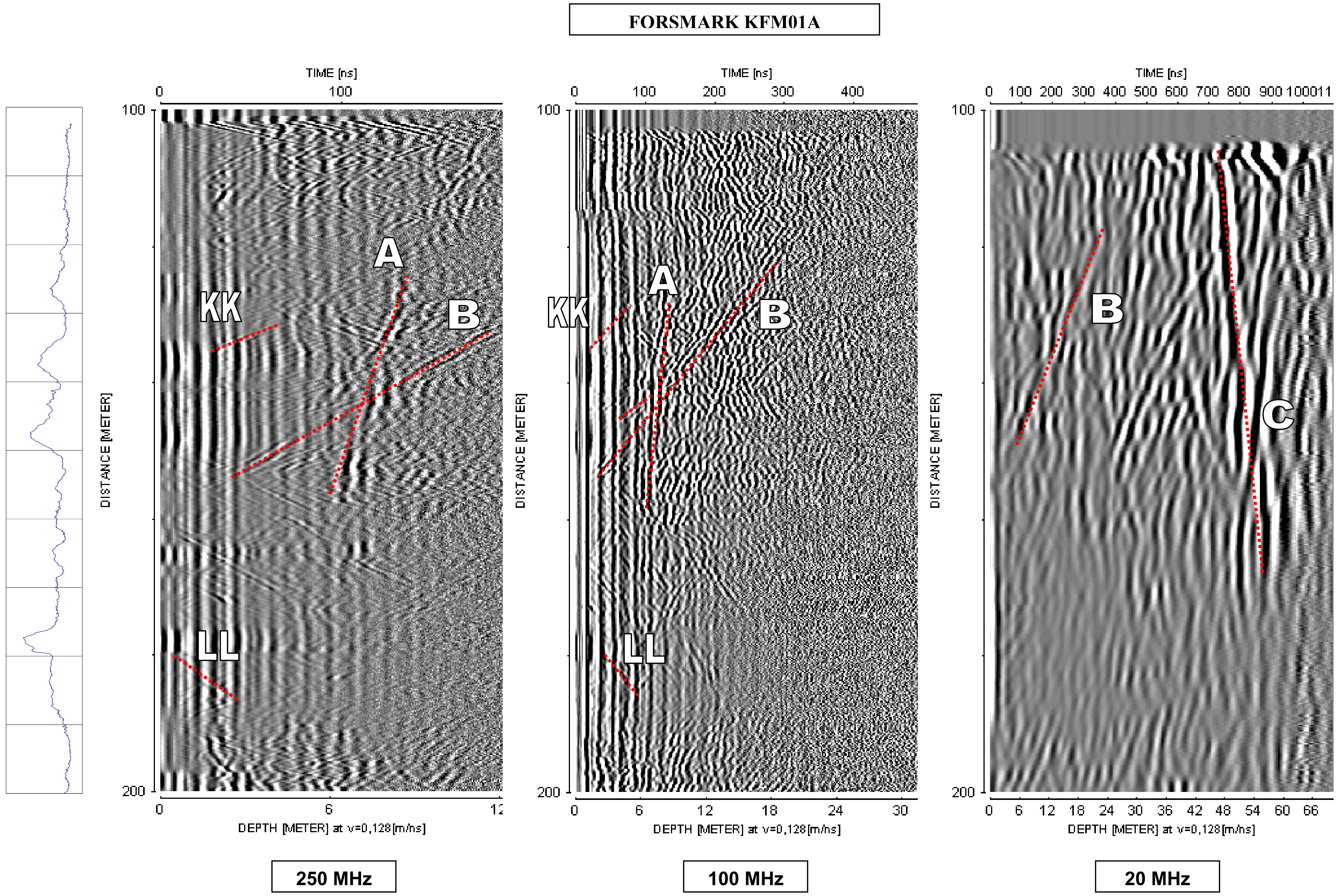
Figure 5-2. Examples of BIPS images suffering from deteriorated quality caused by discolouring of the borehole wall.

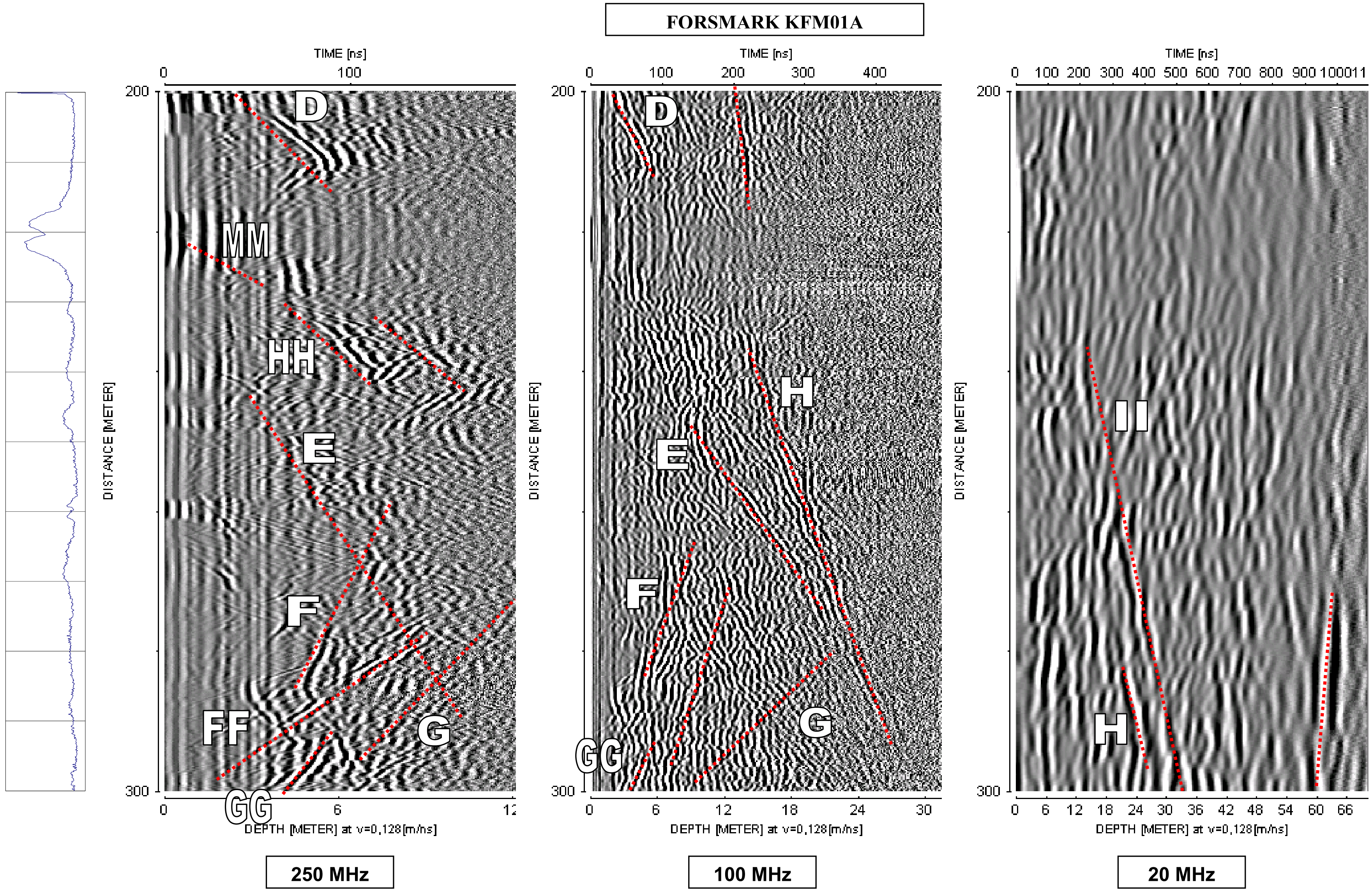
6 References

/1/ **Gustafsson C, Nilsson P, 2003.** Geophysical Radar and BIPS logging in borehole HFM01, HFM02, HFM03 and the percussion drilled part of KFM01A. SKB P-03-41. Svensk Kärnbränslehantering AB.

Appendix 1

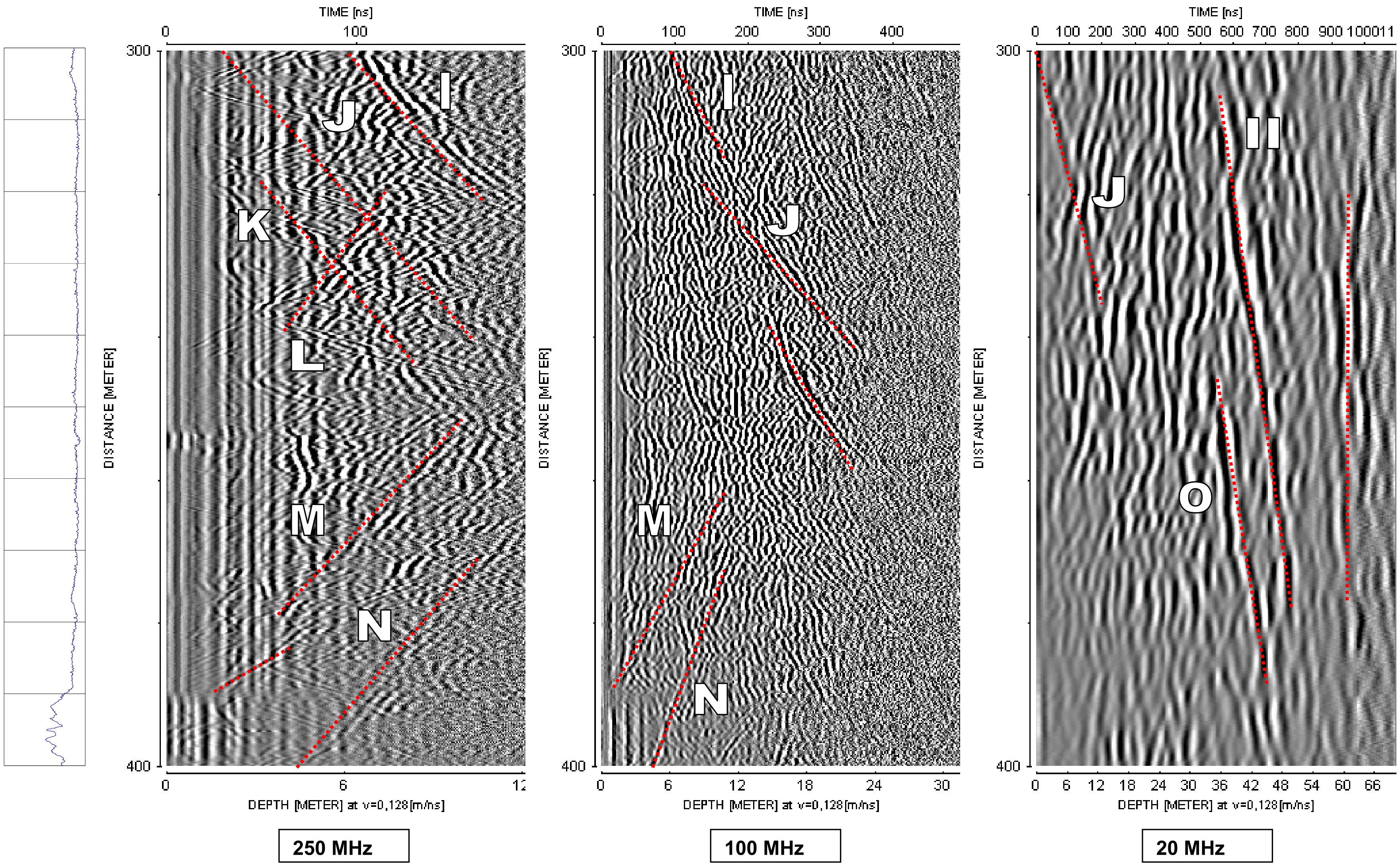
Radar logging of KFM01A
Dipole antennas 250, 100 and 20 MHz

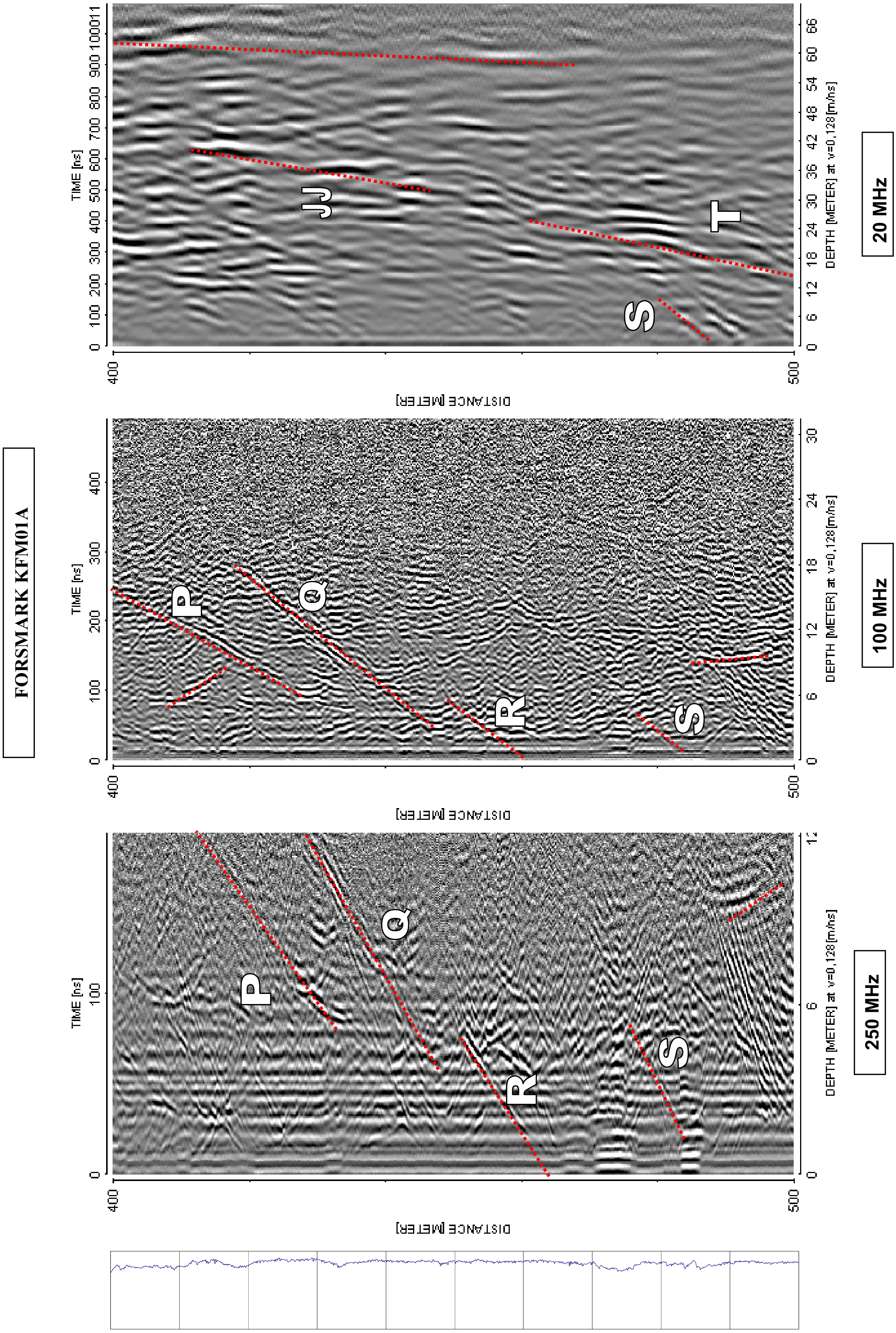

FORSMARK KFM01A
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128 [m/ns]
KK
A
B
LL
C
250 MHz
100 MHz
20 MHz

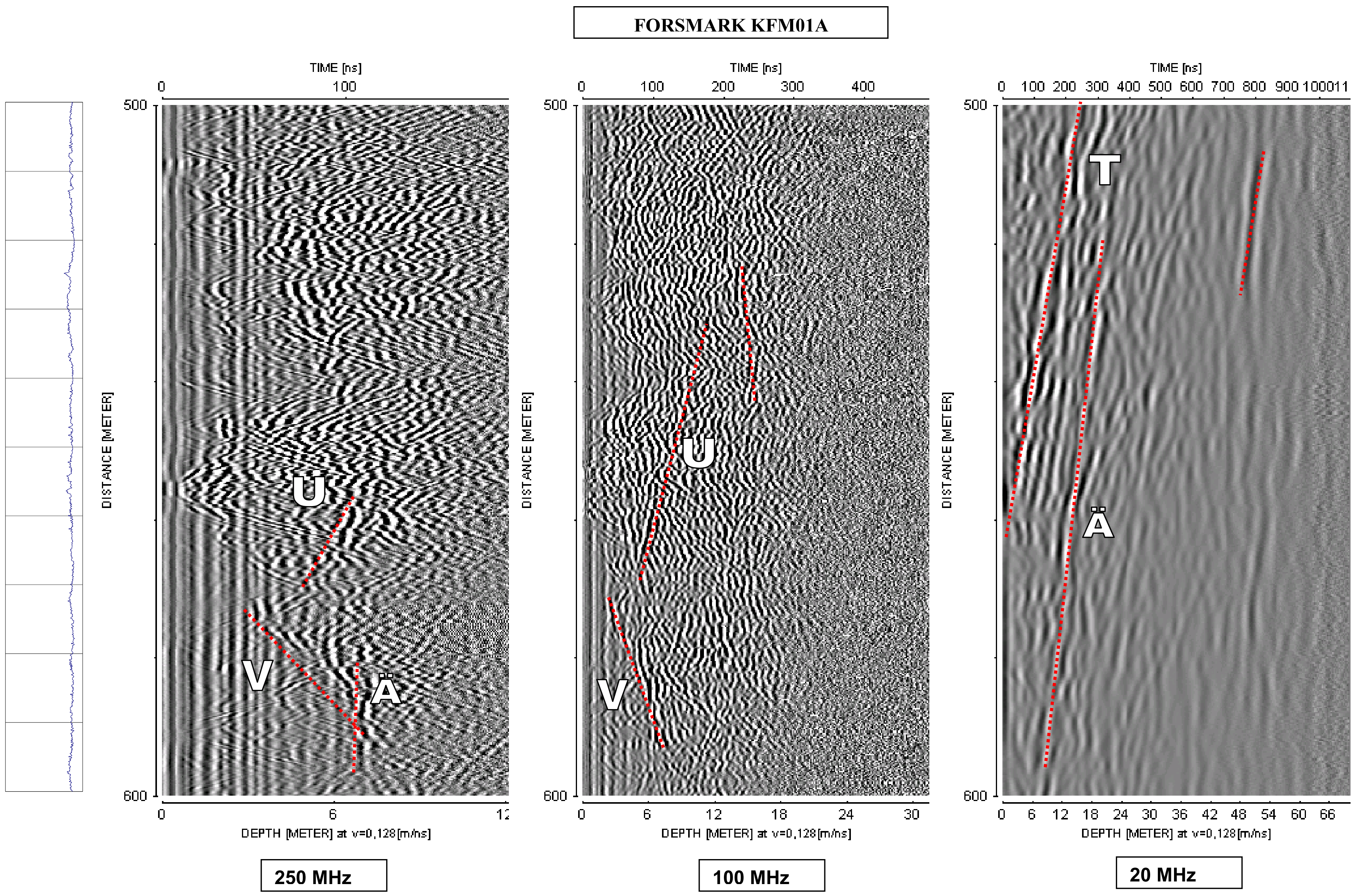


FORSMARK KFM01A
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128 [m/ns]
D
MM
HH
E
F
FF
G
GG
H
II
250 MHz
100 MHz
20 MHz

FORSMARK KFM01A




FORSMARK KFM01A
20 MHz
100 MHz
250 MHz
TIME [ns]
DEPTH [METER] at v=0,128 [m/ns]
DISTANCE [METER]
JJ
T
S
P
Q
R


FORSMARK KFM01A
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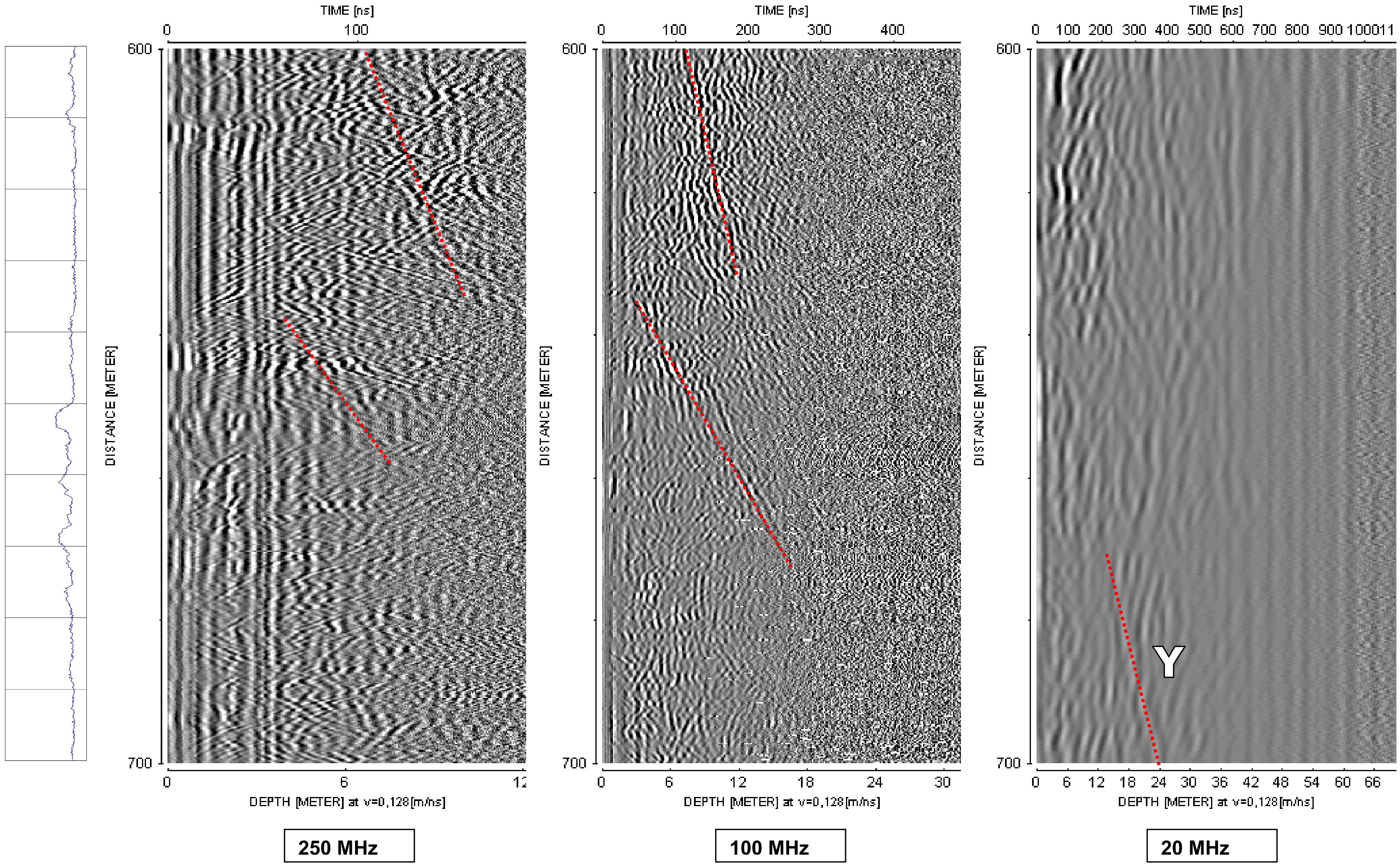
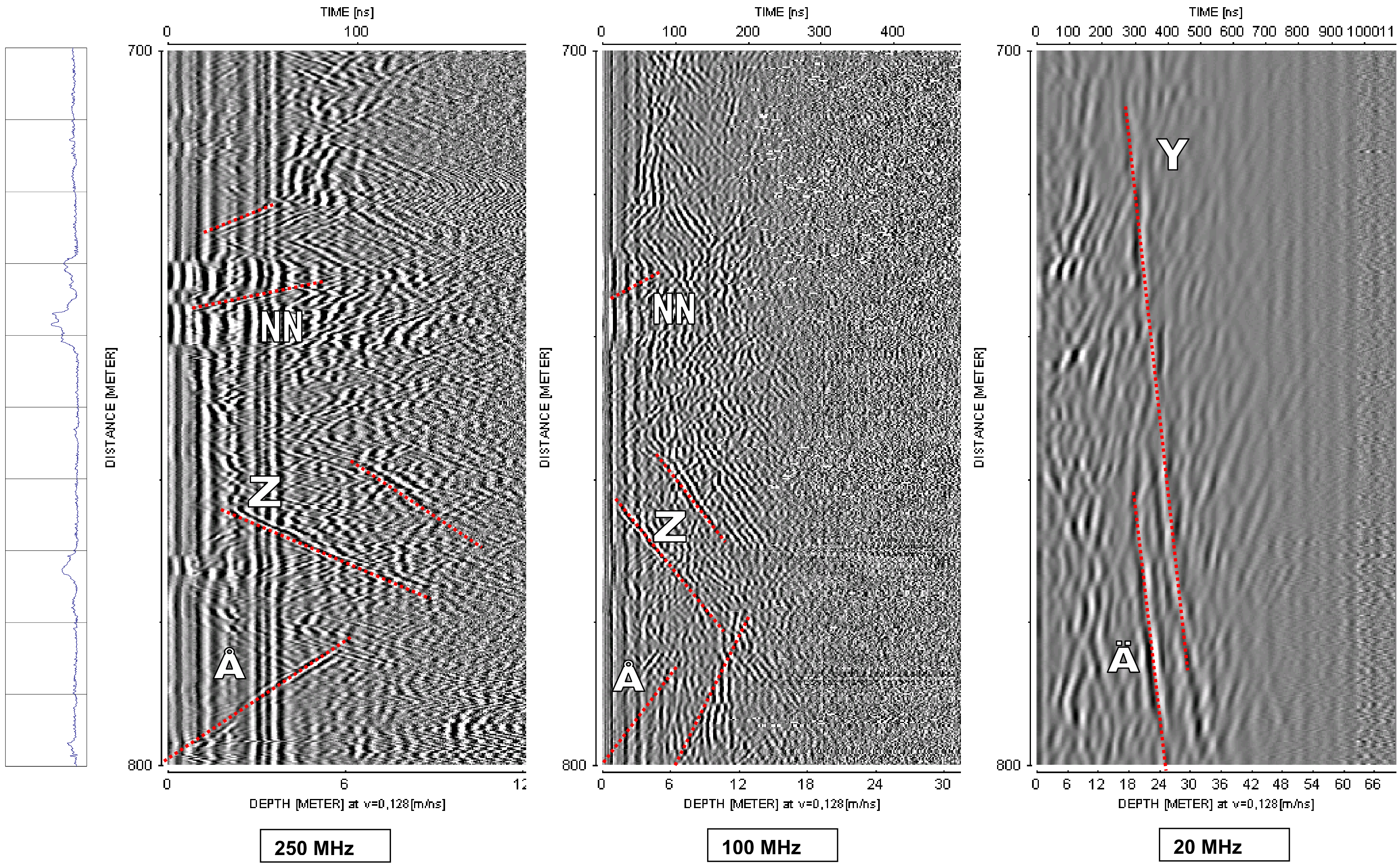
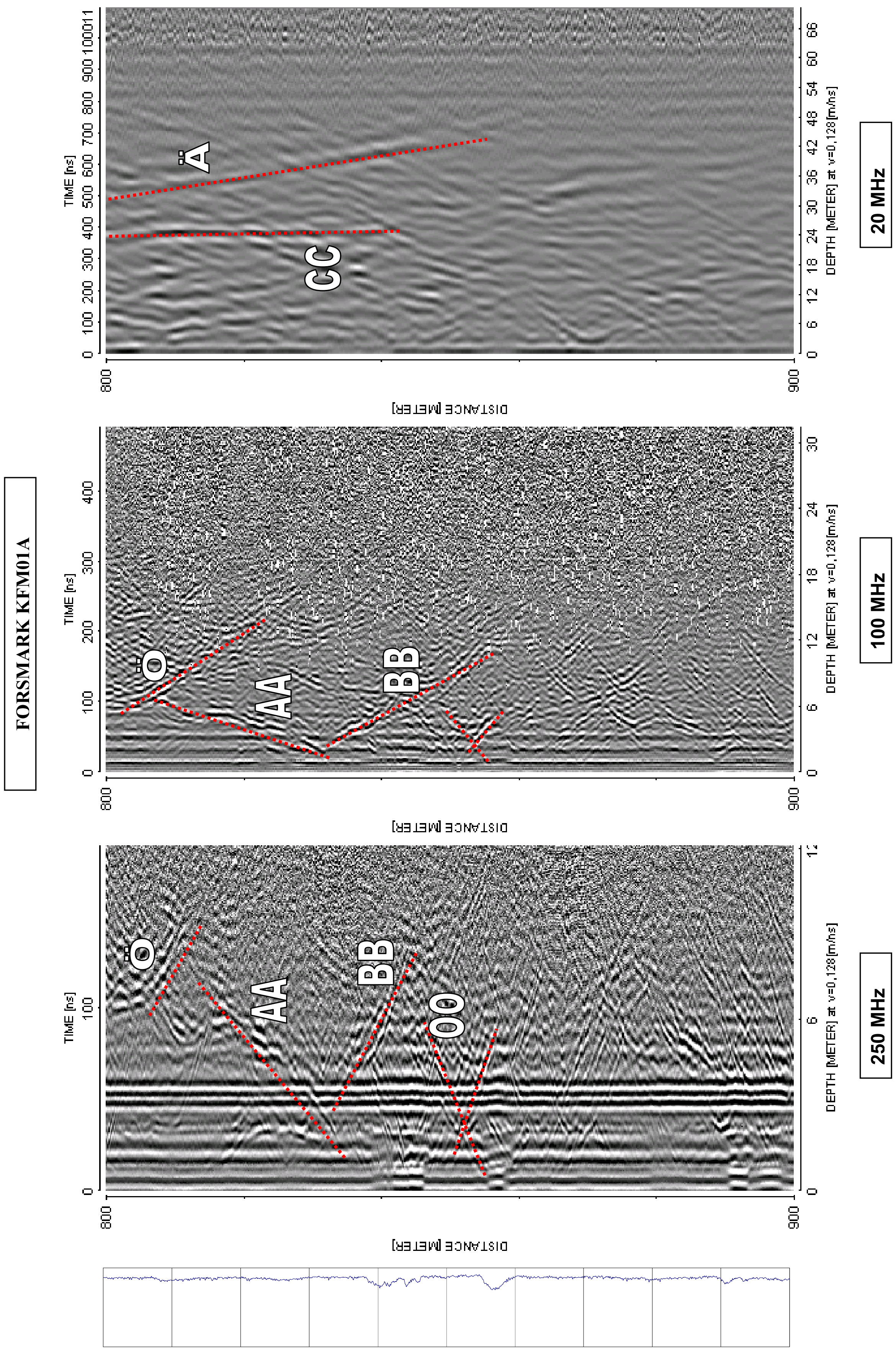
20 MHz

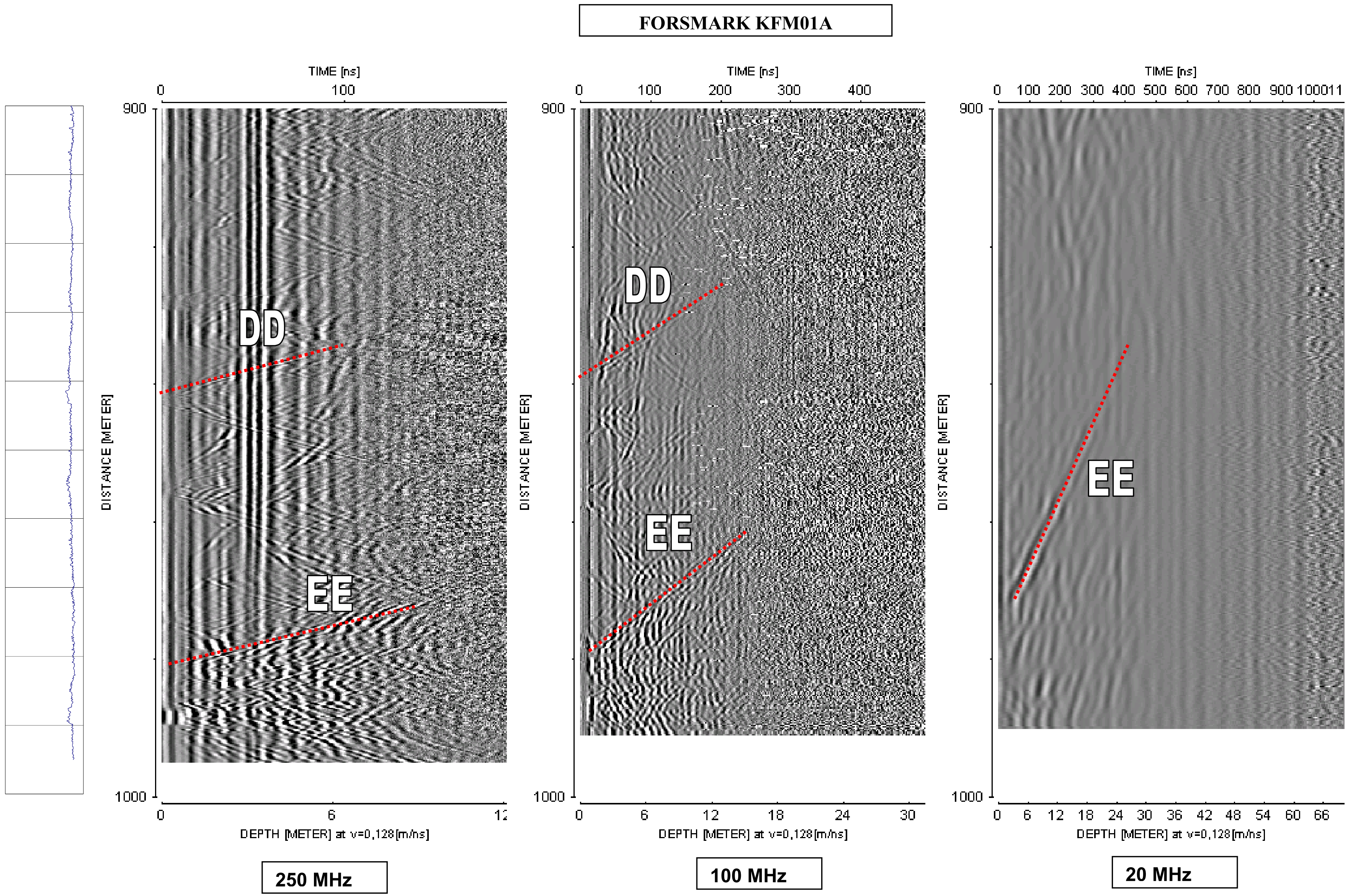
FORSMARK KFM01A



FORSMARK KFM01A




FORSMARK KFM01A
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128[m/ns]
20 MHz
100 MHz
250 MHz
Ä
CC
Ö
AA
BB
OO


FORSMARK KFM01A
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,128 [m/ns]
DD
EE
250 MHz
100 MHz
20 MHz