P-04-66

Revised April 2006

Oskarshamn site investigation

RAMAC logging with directional radar antenna in boreholes KSH01A, KSH01B and KSH02

Jaana Gustafsson, Christer Gustafsson
Malå Geoscience AB/RAYCON

April 2004

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-04-66

Revised April 2006

Oskarshamn site investigation

RAMAC logging with directional radar antenna in boreholes KSH01A, KSH01B and KSH02

Jaana Gustafsson, Christer Gustafsson
Malå Geoscience AB/RAYCON

April 2004

Keywords: RAMAC, Radar, Directional radar, Reflectors, Strike, Dip.

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.

Reading instruction

For revision no 1 of this report a recalculation of the directional radar data has been done. The strike angle between the line of the plane's cross-section with the surface and the Magnetic North direction was earlier counted counter-clockwise but it is now recalculated as such it counts clockwise, see Figures 5-2 and 5-3. New values for strike and dip are therefore updated in Tables 5-4 to 5-6.

Abstract

This report includes the data gained in geophysical logging operations performed within the site investigation at Oskarshamn. The logging operations presented here includes borehole radar (RAMAC) with directional radar antenna in the core-drilled boreholes KSH01A, KSH01B and KSH02. All measurements were conducted by Malå Geoscience AB / RAYCON during December 2003.

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 borehole radar data quality from KSH01A, KSH01B and KSH02 was relatively satisfying, but in some parts of lower quality due to more conductive conditions. This conductive environment of course reduces the possibility to distinguish and interpret possible structures in the rock mass which otherwise could give a reflection. However, the borehole radar measurements resulted in a number of identified radar reflectors. In KSH01A over 50 radar reflectors were identified and most of them were also orientated (strike and dip). About 10 radar reflectors were identified in KSH01B and the corresponding number for KSH02 is over 70.

Sammanfattning

Denna rapport omfattar geofysiska loggningar inom platsundersökningsprogrammet för Oskarshamn. Mätningarna som presenteras här omfattar borrhålsradarmätningar (RAMAC) med radar riktantenn i kärnborrhålen KSH01A, KSH01B och KSH02. Alla mätningar är utförda av Malå Geoscience AB /RAYCON under december 2003.

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

Borrhålsradardata från KSH01A, KSH01B och KSH02 var relativt tillfredställande, men tidvis av sämre kvalité troligen till stor del beroende på en konduktiv miljö. En konduktiv miljö minskar möjligheterna att identifiera strukturer ur borrhålsradardata. Dock har drygt 50 radarreflektorer identifierats i KSH01A, varav de flesta har kunnat orienteras (strykning och stupning). Motsvarande antal för KSH01B och KSH02 är cirka 10 respektive 70.

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 Oskarshamn. The logging operations presented here includes borehole radar (RAMAC) measurements with directional radar antenna in the core-drilled boreholes KSH01A, KSH01B and KSH02. This report includes measurements from 80 to approximately 1000 m depth in borehole KSH02, from 100 to 990 m in KSH01A and measurements from approximately 5 to 90 m in borehole KSH01B. The three boreholes are drilled with a diameter of 76 mm. Results from RAMAC measurements with dipole antenna in KSH01A, KSH01B and KSH02 are also reported in /1/ and /2/.

All measurements were conducted by Malå Geoscience AB / RAYCON during February 2004 in accordance with the instructions and guidelines from SKB (Activity plans AP PS 400-03-002 and AP PS 400-03-032 and method description SKB MD 252.020, SKB internal controlling documents) and under supervision of Leif Stenberg, SKB. The location of boreholes KSH01A, KSH01B and KSH02 is shown in Figure 1-1.

The used investigation techniques comprised:

- Borehole radar (Malå Geoscinece AB:s RAMAC system) directional radar antennas.

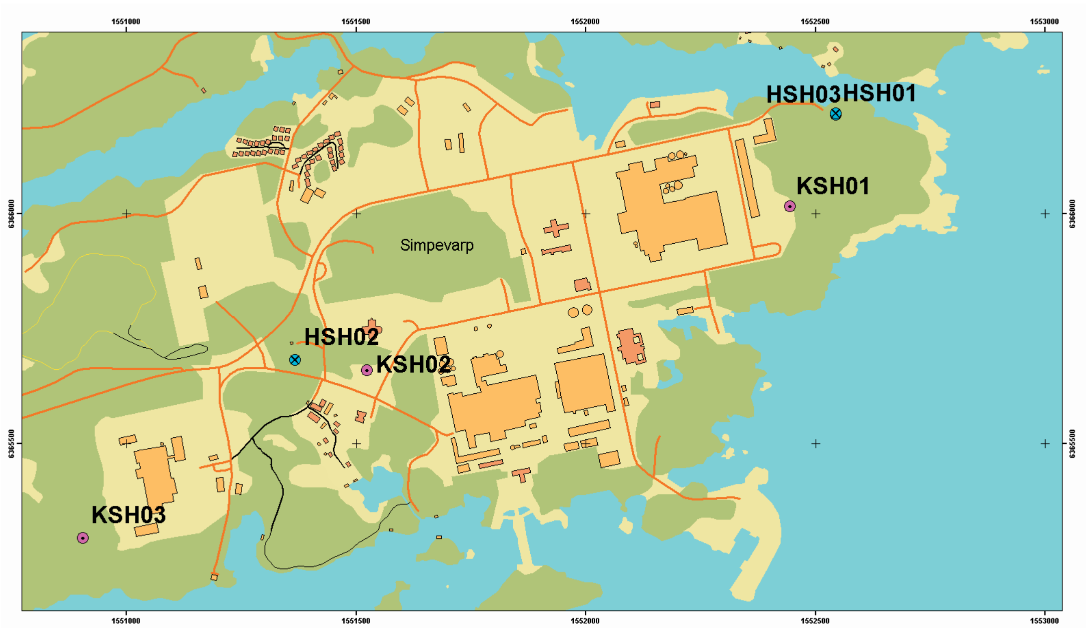


Figure 1-1. *General overview over the Simpevarp subarea.*

2 Objective and scope

The objective of the radar surveys is to receive information from the rock mass around the borehole. Borehole radar was used to investigate the nature and the structure of the rock mass located around the boreholes.

This field report describes the equipment used as well the measurement procedures. 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 document MD 252.021.

The borehole radar system consists of a transmitter and a receiver. During operation an electromagnetic pulse, within the frequency range of 20 MHz up to 250 MHz, is emitted into the bedrock. For the directional antenna a central frequency of 60 MHz is used. 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.

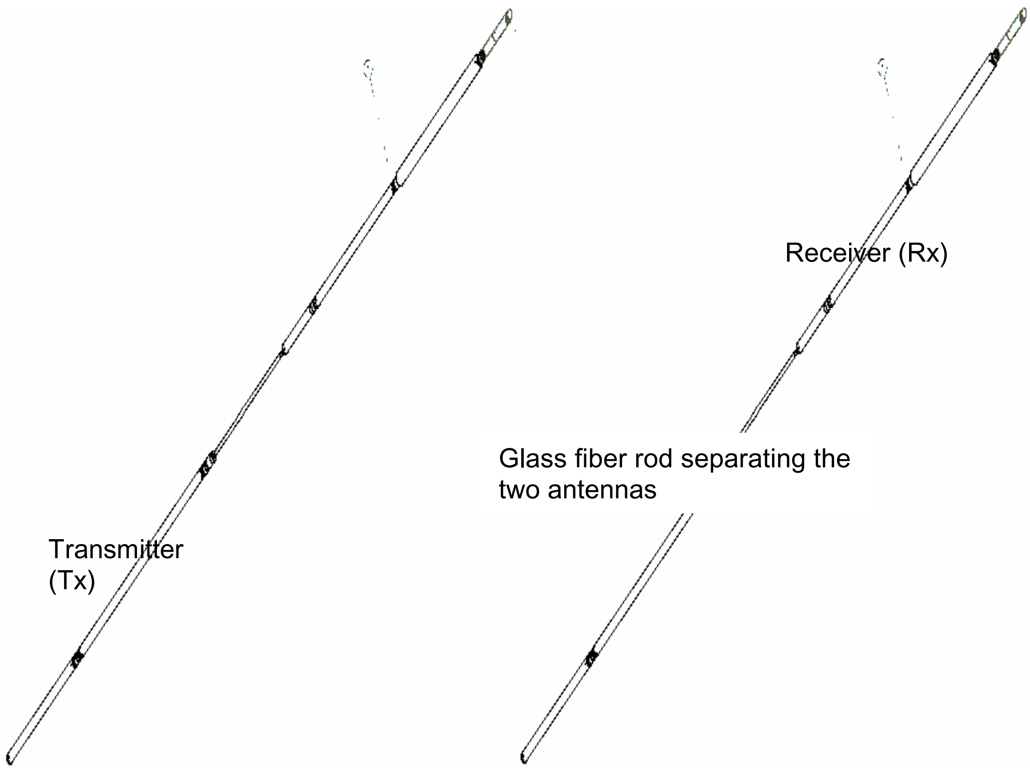


Figure 3-1. *Example of a borehole antenna.*

4 Execution

4.1 Execution of measurements

4.1.1 RAMAC radar

In the boreholes KSH01A, KSH01B and KSH02 the measurements were carried out with directional radar antennas, with a central frequency of 60 MHz.

During logging the directional antennas (transmitter and receiver) were lowered step-wise (with a short pause for each measurement occasion) into the borehole and the data were recorded on the field PC along the measured interval. The antennas are kept at a fixed separation by glass fiber rods according to Table 4-1 to 4-3. See also Figure 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 KSH01A and KSH01B. 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 5 to 20 degrees. This can be considered as satisfying due to the disturbed environment, with metallic objects etc at the test site.

For more information on system settings for the different antennas used in the investigation KSH01A, KSH01B and KSH02 see Table 4-1 to 4-3 below.

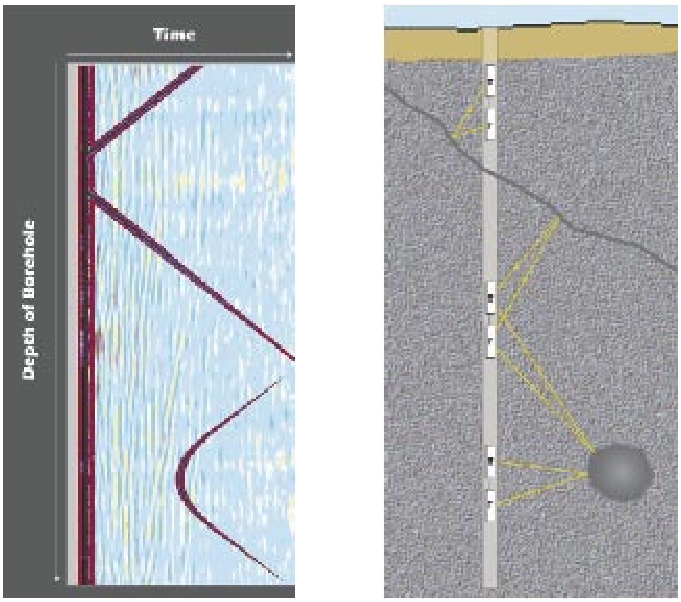


Figure 4-1. *The principle of radar borehole reflection survey and an example of result.*

Table 4-1. Radar logging information from KSH01A.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**
BH:	**KSH01A**	**Equipment:**	**SKB RAMAC**
Type:	**Directional**	**Manufacturer:**	**MALÅ GeoScience**
Operators:	**CG**	**Antenna**	
		Directional (60 MHz)	

Logging date:	2004-02-16
Reference:	T.O.C.
Sampling frequency (MHz):	656
Number of samples:	512
Number of stacks:	32
Signal position:	365.72
Logging from (m):	103
Logging to (m):	985
Trace interval (m):	0.5
Antenna separation (m):	5.73

Table 4-2. Radar logging information from KSH01B.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**
BH:	**KSH01B**	**Equipment:**	**SKB RAMAC**
Type:	**Directional**	**Manufacturer:**	**MALÅ GeoScience**
Operators:	**CG**	**Antenna**	
		Directional (60 MHz)	

Logging date:	2004-02-17
Reference:	T.O.C.
Sampling frequency (MHz):	656
Number of samples:	512
Number of stacks:	32
Signal position:	365.72
Logging from (m):	6
Logging to (m):	90
Trace interval (m):	0.5
Antenna separation (m):	5.73

Table 4-3. Radar logging information from KSH02.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**
BH:	**KSH02**	**Equipment:**	**SKB RAMAC**
Type:	**Directional**	**Manufacturer:**	**MALÅ GeoScience**
Operators:	**CG**	**Antenna**	
		Directional (60 MHz)	

Logging date:	2004-02-17
Reference:	T.O.C.
Sampling frequency (MHz):	656
Number of samples:	512
Number of stacks:	32
Signal position:	365.72
Logging from (m):	80
Logging to (m):	987
Trace interval (m):	0.5
Antenna separation (m):	5.73

4.1.2 Length measurements

During logging the depth recording for the RAMAC and BIPS systems is taken care of by a measuring wheel mounted on the cable winch. During the BIPS logging the logging cable is marked with red scotch tape where the reference marks in the borehole is visible on the image. These tape marks are then used for controlling the RAMAC radar measurements.

The experience we have for the measurements in the core drilled boreholes in Oskarshamn is that the divergence for the marks on the cable is less than 50 cm.

For the measurements with the directional antenna in KSH01A, KSH01B and KSH02 the depth divergence was at most 60 cm. The depth divergence is corrected in the resulting tables in Chapter 5.

4.2 Analyses and interpretation

4.2.1 Radar

The result from radar measurements is most often presented in the form of a radargram where the position of the probes is shown along one axis and the propagation is shown along the other axis. The amplitude of the received signal is shown in the radargram with a grey scale where black colour corresponds to the large positive signals and white colour to large negative signals. Grey colour 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 120 m/micro seconds. The velocity measurement was performed in borehole KSH01B with the 100 MHz dipole antennas /1/.

The visualization of data in Appendix 1 to 3 is made with REFLEX, a Windows based processing software for filtering and analysis of radar data. These Appendixes are also shown in /1/ and /2/, but here also showing structures identified in the 60 MHz directional data. The processing steps for the directional antenna are shown in Table 4-4 to 4-6.

For the interpretation of the intersection angle between the borehole axis and the planes visible on the radargrams the RadinterSKB software has been used. RadinterSKB is also used to interpret the orientation of structures identified in the directional antenna data.

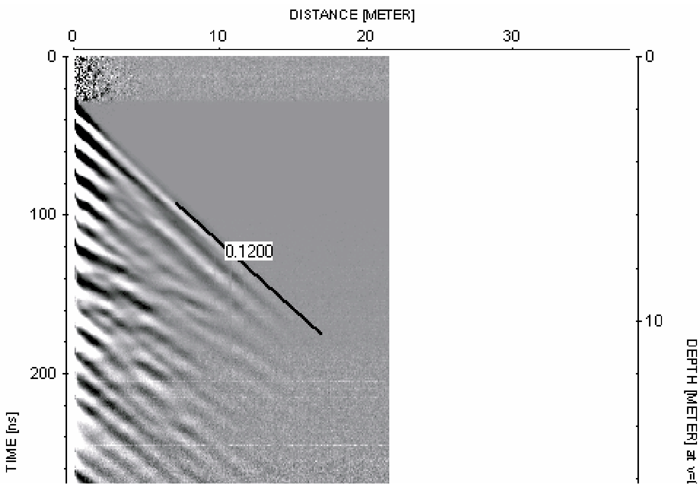


Figure 4-3. *Results from velocity measurements in KSH01B with 100 MHz dipole antennas /1/.*

The interpreted intersection points and intersection angles of the detected structures are presented in the Table 5-4 to 5-6 and are also visible on the radargrams in Appendix 1 to 3.

Table 4-4. Processing steps for borehole radar data in KSH01A.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**
BH:	**KSH01A**	**Equipment:**	**SKB RAMAC**
Type:	**Directional**	**Manufacturer:**	**MALÅ GeoScience**
Interpret:	**JA**	**Antenna Directional**	
Processing:		DC removal	
		Move start time	
		FIR	
		Gain	

Table 4-5. Processing steps for borehole radar data in KSH01B.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**
BH:	**KSH01B**	**Equipment:**	**SKB RAMAC**
Type:	**Directional**	**Manufacturer:**	**MALÅ GeoScience**
Interpret:	**JA**	**Antenna Directional**	
Processing:		DC removal	
		Move start time	
		FIR	
		Gain	

Table 4-6. Processing steps for borehole radar data in KSH02.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**
BH:	**KSH02**	**Equipment:**	**SKB RAMAC**
Type:	**Directional**	**Manufacturer:**	**MALÅ GeoScience**
Interpret:	**JA**	**Antenna Directional**	
Processing:		DC removal	
		Move start time	
		FIR	
		Gain	

4.3 Nonconformities

For revision no 1 of this report a recalculation of the directional radar data has been done. The strike angle between the line of the plane's cross-section with the surface and the Magnetic North direction was earlier counted counter-clockwise but it is now recalculated as such it counts clockwise, see Figures 5-2 and 5-3. New values for strike and dip are therefore updated in Tables 5-4 to 5-6.

5 Results and data delivery

The results from the radar measurements were delivered as raw data on CD-ROM:s to SKB directly after the termination of the field activities. The information of the measurements was registered in SICADA, and the CD-ROM:s stored by SKB.

The RAMAC radar data was delivered as raw data (fileformat *.rd3 or *.rd5) for KSH01A, KSH01B and KSH02 with corresponding information files (file format *.rad) whereas the data processing steps and results are presented in this report.

The delivered raw and processed data have been inserted in the database of SKB (SICADA). The SICADA reference to the present activity is field notes 240 and 241 respectively.

5.1 RAMAC logging

The results of the interpretation of the radar measurements are presented in Tables 5-1 to 5-6 below. Radar data from the dipole antennas in KSH01A, KSH01B and KSH02 is also visualized in Appendix 1 to 3. See also /1/ and /2/. It should be remembered that the images in Appendix 1 to 3 are only composite pictures of all events 360 degrees around the borehole, and do not reflect the orientation of the structures.

Only the larger clearly visible structures are interpreted in RadinterSKB. A number of minor structures also exist, indicated in Appendix 1 to 3. It should also be pointed out that reflections interpreted will in some cases not reach the borehole. As seen in Appendix 1 to 3 the listed structures in Table 5-4 to 5-6 can be identified in the data from more than one antenna frequency

The data quality from KSH01A, KSH01B and KSH02 is relatively satisfying, but in some parts of lower quality due to more conductive conditions. A conductive environment makes the radar wave to attenuate, which decreases the penetration. This is for instance seen quite clearly in the data from KSH02 from a depth of 280 to 305 m. A conductive environment may also cause so-called ringing in the data, illustrated for example from 825 m and downwards in KSH01A. This may make it hard to distinguish the correct direction to the identified structure. See Figure 5-1 below.

As also seen in Appendix 1 to 3 the resolution and penetration of radar waves depend of the antenna frequency used. Low antenna frequency gives less resolution but higher penetration rate compared to a higher frequency.

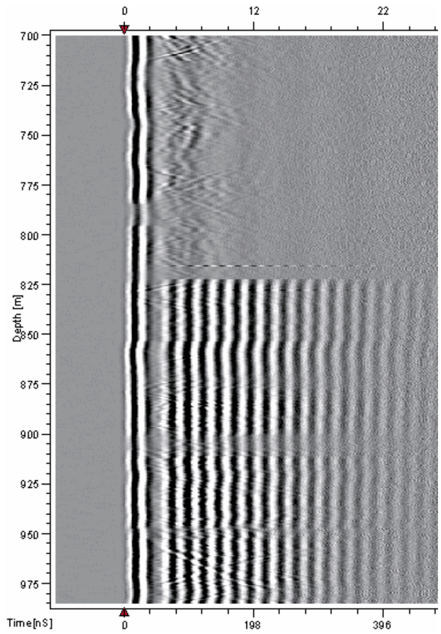


***Figure 5-1**. Example of the so-called ringing in the radar data. This is for example clearly seen in the data from 825 m depth in KSH01A.*

In Tables 5-1 to 5-3 below the identified structures are listed for the three different boreholes.

Table 5-1. Distribution of identified structures in KSH01A.

Intersection Depth	KSH01A
0–50	–
50–100	–
100–150	3
150–200	4
200–250	6
250–300	3
300–350	4
350–400	5
400–450	2
450–500	1
500–550	3
550–600	4
600–650	2
650–700	3
700–750	3
750–800	3
800–850	3
850–900	1
900–950	2
950–1000	1

Table 5-2. Distribution of identified structures in KSH01B.

Intersection Depth	KSH01B
0–10	–
10–20	–
20–30	1
30–40	3
40–50	1
50–60	2
60–70	2
70–80	1
80–90	–
90–100	2

Table 5-3. Distribution of identified structures in KSH02.

Intersection Depth	KSH02
0–50	1
50–100	2
100–150	5
150–200	7
200–250	2
250–300	2
300–350	3
350–400	2
400–450	4
450–500	5
500–550	2
550–600	3
600–650	4
650–700	3
700–750	5
750–800	2
800–850	7
850–900	3
900–950	5
950–1000	4

Tables 5-4 to 5-6 summarises the interpretation of radar data from KSH01A, KSH01B and KSH02. As seen some radar reflectors are marked with ±, which indicates an uncertainty in the interpretation of the direction to the reflector. The direction can in these cases be ±180 degrees. The direction to the reflector (the plane) is defined in Figure 5-2 and 5-3. If the borehole inclination is less than 85° the direction to object is calculated using gravity roll (Figure 5-2). If the borehole is near vertical (> 85 degrees) the direction to object is calculated using magnetic roll (Figure 5-3). The direction to object and the intersection angle are recalculated to strike and dip, also given in Tables 5-4 to 5-6. The plane strike is the angle between line of the plane's cross-section with the surface and the Magnetic North direction. It counts clockwise and can be between 0 and 359 degrees. A strike of 0 degrees implies a dip to the east while a strike of 180 degrees implies a dip to the west. The plane dip is the angle between the plane and the surface. It can vary between 0 and 90 degrees.

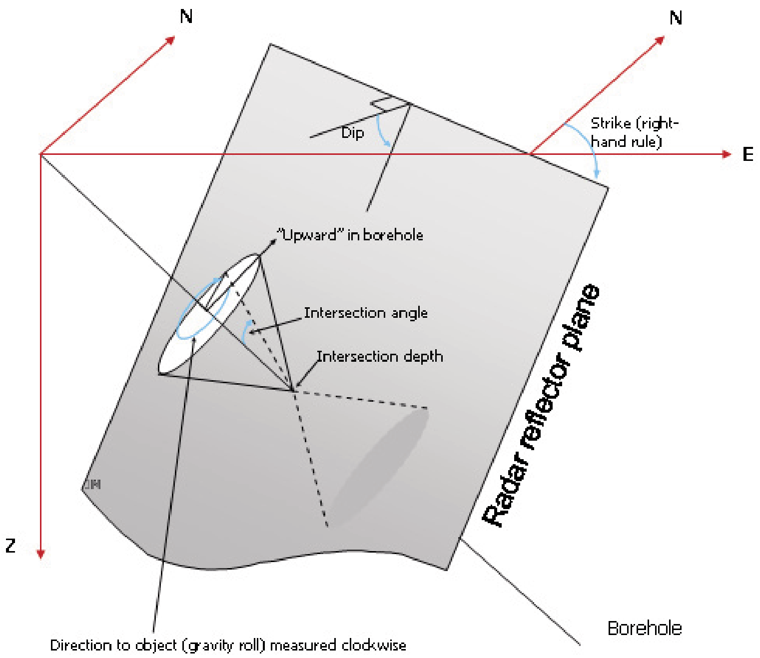


Figure 5-2. *Definition of intersection angle, direction to object using gravity roll, dip and strike using the right hand rule as presented in Table 5-4.*

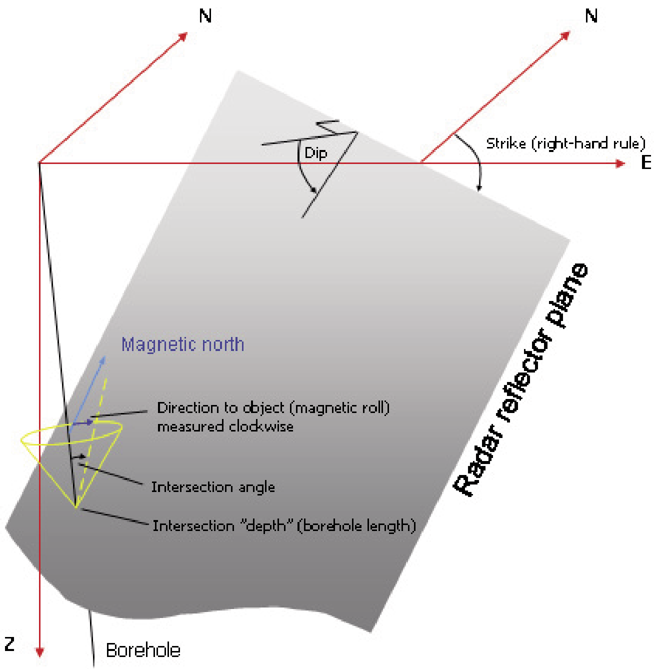


Figure 5-3. *Definition of intersection angle, direction to object using magnetic roll, dip and strike using the right hand rule as presented in Tables 5-5 and 5-6.*

Table 5-4. Interpretation of dipole antennas 20, 100 and 250 MHz and the directional antenna from KSH01A.

RADINTER MODEL INFORMATION
(20, 100 and 250 MHz Dipole Antennas and directional antenna)

Site:	**Oskarshamn**
Borehole name:	**KSH01A**
Nominal velocity (m/μs):	**120.0**

Name	**Intersection depth**	**Intersection angle**	**Direction to object (gravity roll)**	**Interpreted Dip/Strike 1**	**Interpreted Dip/Strike 2**
A	141.5	23	114	63 / 357	
Bx	143.1	42	225 ±	39 / 124	59 / 286
B	145.0	25			
CC	171.3	73	48	32 / 281	
C	171.4	31	75	66 / 322	
D	191.3	31	87	58 / 332	
EE	199.4	70	240 ±	20 / 166	32 / 289
FF	205.4	30			
Ex	209.3	58	30	47 / 274	
E	212.5	16			
F	215.2	55	12 ±	48 / 262	20 / 92
FFx	223.5	51	189	25 / 87	
Fxx	244.8	50	3	54 / 257	
Fx	252.8	50	30	53 / 279	
1	270.6	56	18	47 / 267	
1x	289	58	324	43 / 229	
2	311.2	45	324 ±	57 / 226	34 / 29
3	312.4	65	327 ±	37 / 235	15 / 15
4	332.6	73	342	31 / 248	
5	342.1	45	324	57 / 230	
G	364.8	36	135	45 / 26	
Z	381.5	47			
H	383.3	30	264 ±	58 / 173	61 / 335
HH	395.6	71	36	48 / 285	
Zx	397.6	39	48	62 / 302	
I	409.2	31	81 ±	54 / 333	49 / 177
J	447.9	11	312	89 / 218	
JJ	450.9	21	204	54 / 113	
Kx	504.7	53	150	25 / 43	
K	510.4	13			
L	542.4	20			
M	561.1	52	39	48 / 299	
Mx	566.2	52	177	23 / 87	
N	579.3	51	246 ±	33 / 181	45 / 325
O	590.6	46	36	54 / 302	
Ox	614	61	33	42 / 297	
P	628.2	34	69	55 / 333	
Q	667.4	47	111	43 / 18	
Qxx	680.3	13	333	90 / 70	
Qx	681.6	39	69	58 / 338	
R	703.5	16	266	71 / 182	
S	720.0	58	177	24 / 100	

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas and directional antenna)					
Site:		**Oskarshamn**			
Borehole name:		**KSH01A**			
Nominal velocity (m/μs):		**120.0**			
Name	**Intersection depth**	**Intersection angle**	**Direction to object (gravity roll)**	**Interpreted Dip/Strike 1**	**Interpreted Dip/Strike 2**
Sx	747.4	63	147 ±	17 / 34	41 / 264
Sxx	763.3	41	321 ±	62 / 254	38 / 55
Sxxx	770.4	32	141	46 / 56	
SS	789.5	41	138	38 / 52	
TT	816.2	38	90 ±	54 / 4	54 / 210
T	834.7	66	3 ±	41 / 295	7 / 123
Y	838.4	21			
Tx	876.5	51	231 ±	31 / 187	52 / 331
X	922.1	47	207 ±	26 / 160	60 / 315
W	944.6	23	333 ±	84 / 272	49 / 83
U	985.7	40	12 ±	69 / 307	28 / 136

Names in table according to Appendix 1.

Table 5-5. Interpretation of dipole antennas 20, 100 and 250 MHz and the directional antenna from KSH01B.

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas and Directional antenna)					
Site:		**Oskarshamn**			
Borehole name:		**KSH01B**			
Nominal velocity (m/μs):		**120.0**			
Name	**Intersection depth**	**Intersection angle**	**Direction to object (magnetic roll)**	**Interpreted Dip/Strike 1**	**Interpreted Dip/Strike 2**
BB	24.2	52	198	38 / 288	
AAA	30.3	48	192 ±	42 / 282	42 / 102
B	33.5	30			
BBB	36.8	52	204 ±	38 / 294	38 / 114
C	48.8	40			
CC	50.3	54	207	36 / 297	
A	55.2	21			
AA	63	24	99	66 / 189	
E	69.5	50	75 ±	32 / 165	32 / 345
D	73.6	50	240	39 / 330	
DD	96.4	54	123 ±	36 / 213	36 / 33
EE	99	61	351 ±	29 / 81	29 / 261

Names in table according to Appendix 2.

Table 5-6. Interpretation of dipole antennas 20, 100 and 250 MHz and the directional antenna from KSH02.

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas and Directional antenna)					
Site:		**Oskarshamn**			
Borehole name:		**KSH02**			
Nominal velocity (m/μs):		**120.0**			
Name	**Intersection depth**	**Intersection angle**	**Direction to object (magnetic roll)**	**Interpreted Dip/Strike 1**	**Interpreted** Dip/Strike 2
EEE	16.5	10	279	84 / 8	
A	92.6	37			
B	94.4	22			
C	108.1	19			
Cx	115.2	56	165	34 / 255	
D	125.7	53	351	34 / 81	
EEEE	135.3	15			
Dx	147.5	59	171	32 / 261	32 / 81
Dxx	160.4	58	351	32 / 81	32 / 261
E	170.6	24			
Ex	172.3	60	195	30 / 285	
F	174.7	17	180	71 / 270	
Fx	181	52	183	38 / 273	
GG	188.1	10	354	80 / 84	
Fxx	198.8	61	357	29 / 87	29 / 267
EE	218.1	25			
Fz	228.3	42	207	48 / 297	48 / 117
FF	276.7	72			
Gx	294.8	59	276	31 / 6	31 / 186
G	302.2	59	342	34 / 72	
H	344.2	44	264	45 / 354	45 / 174
I	345.6	29	186	61 / 276	
J	364.3	56	222	30 / 252	30 / 132
L	395.5	55	165	37 / 255	
Lx	400.4	56	186	34 / 276	
K	401.9	15	159	75 / 249	
Kx	419.4	53	36	37 / 126	37 / 306
M	423.7	33	212	58 / 302	
N	467.5	51	111	39 / 201	
Nx	472.8	53	189	37 / 279	37 / 99
O	476.7	60	57	34 / 300	
Ox	482.2	56	18	34 / 108	34 / 288
P	498.8	69	240	23 / 330	
Pxx	519.4	21	321	69 / 51	
Px	523.8	13	147	77 / 237	
Q	556.0	69	144	19 / 234	
R	578.5	90	33	0 / 123	
S	590.8	50	288	37 / 18	37 / 198
T	603.6	58	198	35 / 288	
TT	620.2	73	144	24 / 234	
Ux	633.7	65	174	25 / 264	25 / 84

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas and Directional antenna)					
Site:		**Oskarshamn**			
Borehole name:		**KSH02**			
Nominal velocity (m/μs):		**120.0**			
Name	**Intersection depth**	**Intersection angle**	**Direction to object (magnetic roll)**	**Interpreted Dip/Strike 1**	**Interpreted** Dip/Strike 2
U	635.0	74			
V	656.3	70	192	22 / 282	
W	678.3	49	3	40 / 93	
Wx	679.6	58	189	33 / 279	
X	695.6	70	219	24 / 309	24 / 129
Y	702.9	62			
Z	707.4	62	324	31 / 54	
Zx	710.4	74	183	16 / 273	
1	727.5	66	261	26 / 351	
2	739.6	75			
3	759.7	53	300	37 / 30	
4	780.5	75	0	15 / 90	
5	807.7	60	225	29 / 315	
5a	809.5	24			
6x	822.5	62	48	28 / 138	
6xx	826.5	58	30	32 / 120	32 / 300
6a	828.4	23			
6	828.8	61	282	27 / 12	
7	837.6	60			
8	853.5	77			
10	860.4	19	168	69 / 258	69 / 78
9	895.8	23	324	66 / 54	66 / 234
19	906.8	35	279	55 / 9	55 / 189
11	911.2	54			
18	920.9	41			
13	923.7	44			
14	941.7	77	276	19 / 6	19 / 186
17	963.4	63			
15	976.9	87			
16	995.5	41			
12	999.3	12	90	76 / 180	76 / 0

Names in table according to Appendix 3.

In the first column of Appendix 1 to 3, the amplitude of the first arrival is plotted against the depth, for the 250 MHz dipole antennas. The x- axis represents the amplitude, with low amplitudes to the left and higher amplitudes to the right. The y- axis corresponds to the depth of the radargrams. The amplitude variation along the borehole indicates changes in conductivity of the material. A decrease in this amplitude may indicate crushed zones, clay or parts with higher water content, which attenuates the signal due to higher conductivity in the media. Zones with larger decreases in amplitude are presented in Tables 5-7 to 5-9 below.

Table 5-7. Decrease in radar amplitude in borehole KSH01A.

KSH01A	
135–150	405–410
165–170	420–455
195–200	500–505
200–215	555–560
235–290	565–570
300–305	585–590
310–315	625–630
340–345	785–800
380–385	950–955
390–395	980–985

Table 5-8. Decrease in radar amplitude in borehole KSH01B.

KSH01B
20
30
50
60–65
75–80

Table 5-9. Decrease in radar amplitude in borehole KSH02.

KSH02	
80	590
110–105	620
110	635
170	645
190	655
280–310	710
330	730
345–350	735–745
365	760
390–410	780
445	810
490	860
510–520	890
550	970
570	995
580	

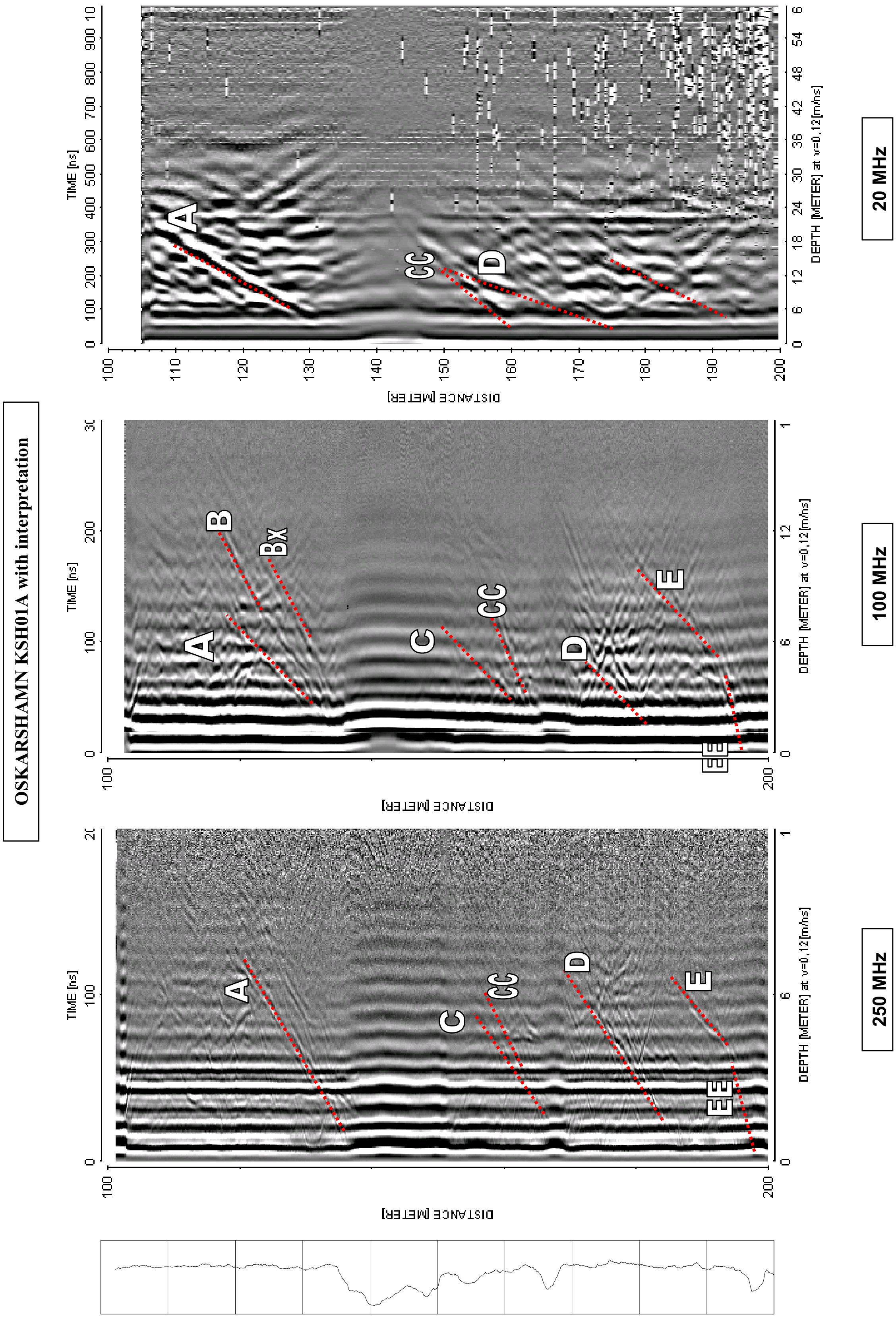
References

/1/ **Aaltonen J, Nilsson P, Gustafsson C, 2003.** Oskarshamn site investigation. RAMAC and BIPS logging and deviation measurements in boreholes KSH01A, KSH01B and the upper part of KSH02. SKB P-03-73. Svensk Kärnbränslehantering AB.

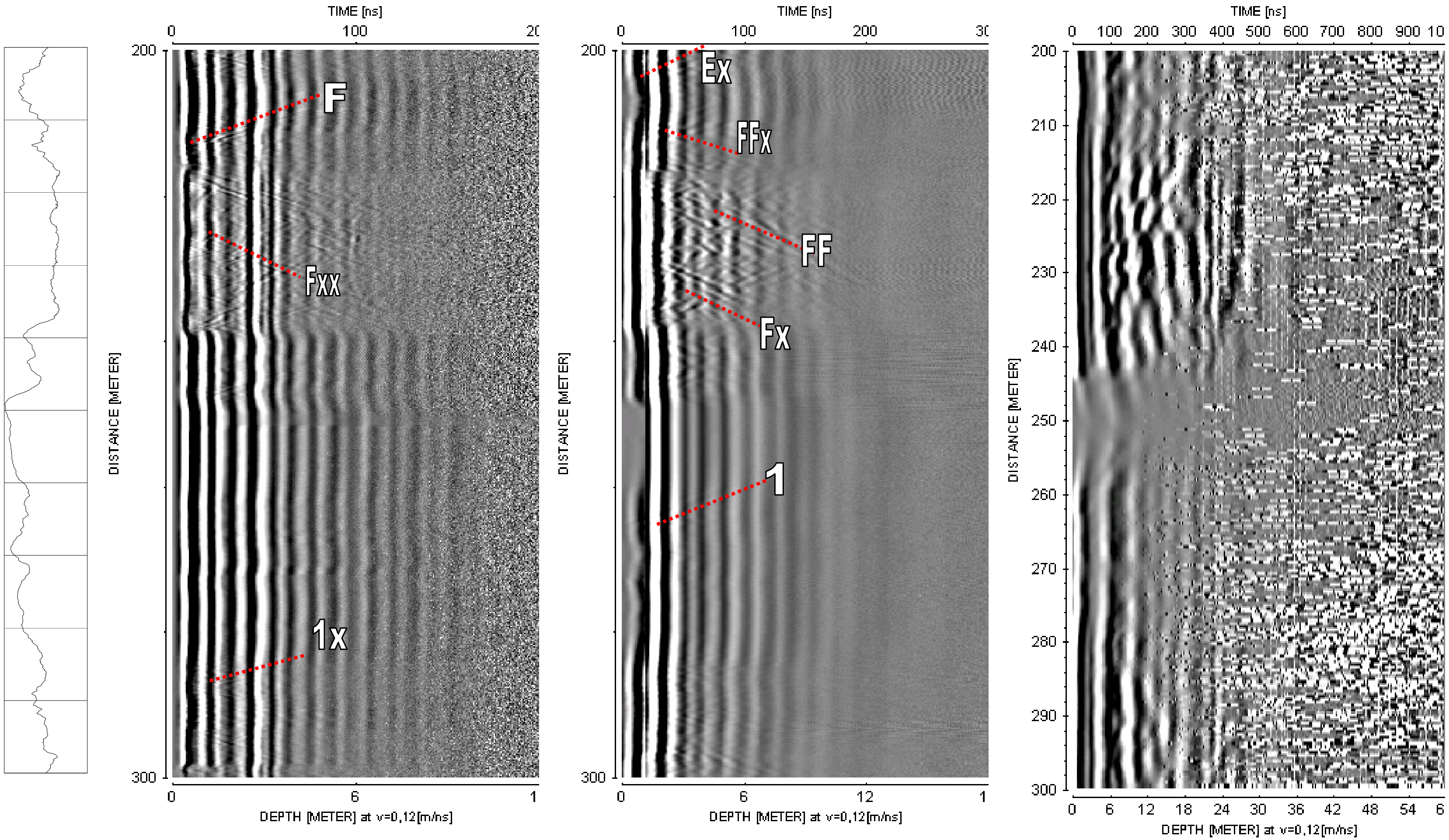
/2/ **Aaltonen J, Gustafsson C, 2003.** Oskarshamn site investigation. RAMAC and BIPS logging in borehole KSH02. SKB P-03-109. Svensk Kärnbränslehantering AB.

Appendix 1

Radar logging in KSH01A with dipole antennas 250, 100 and 20 MHz



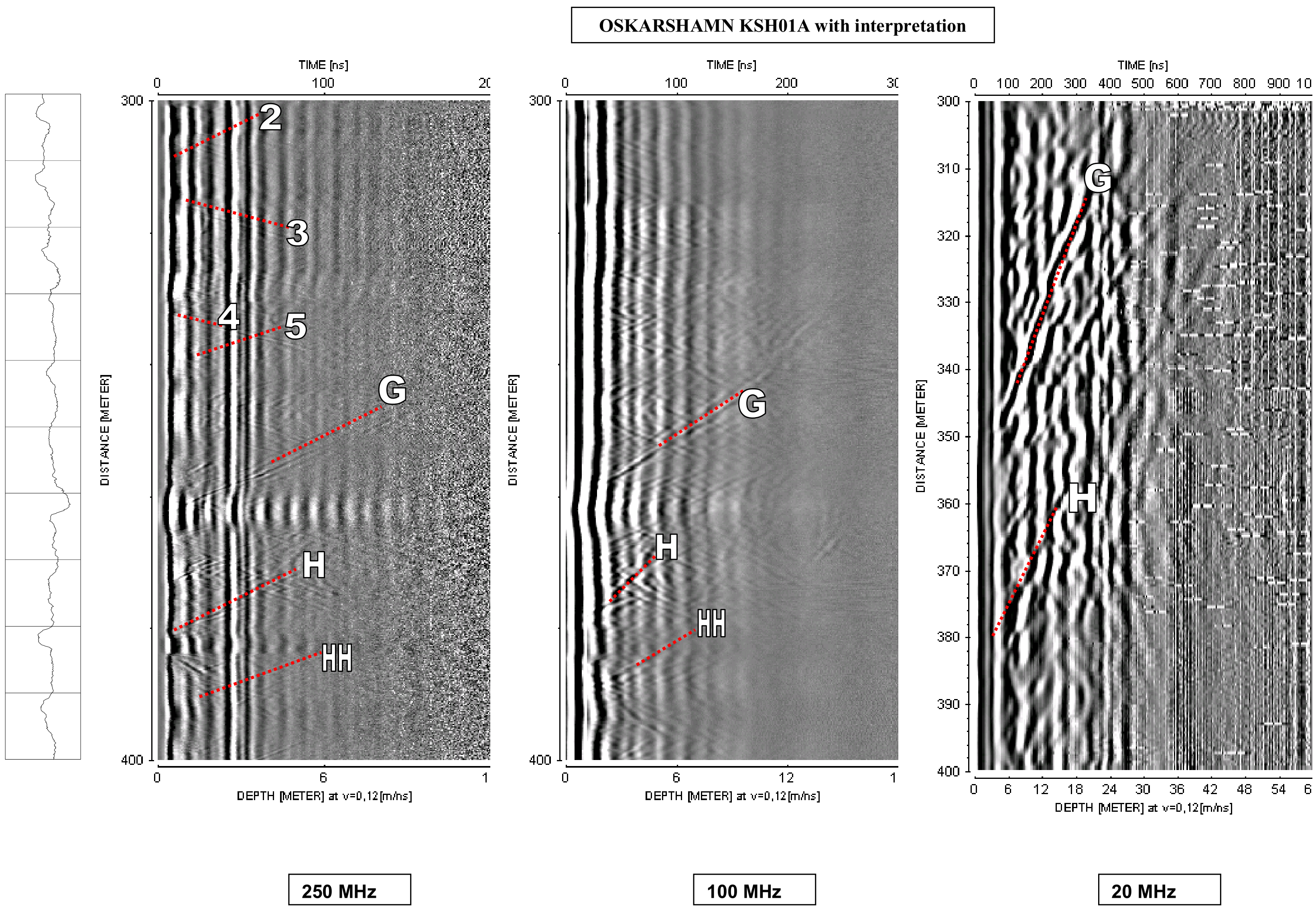
OSKARSHAMN KSH01A with interpretation



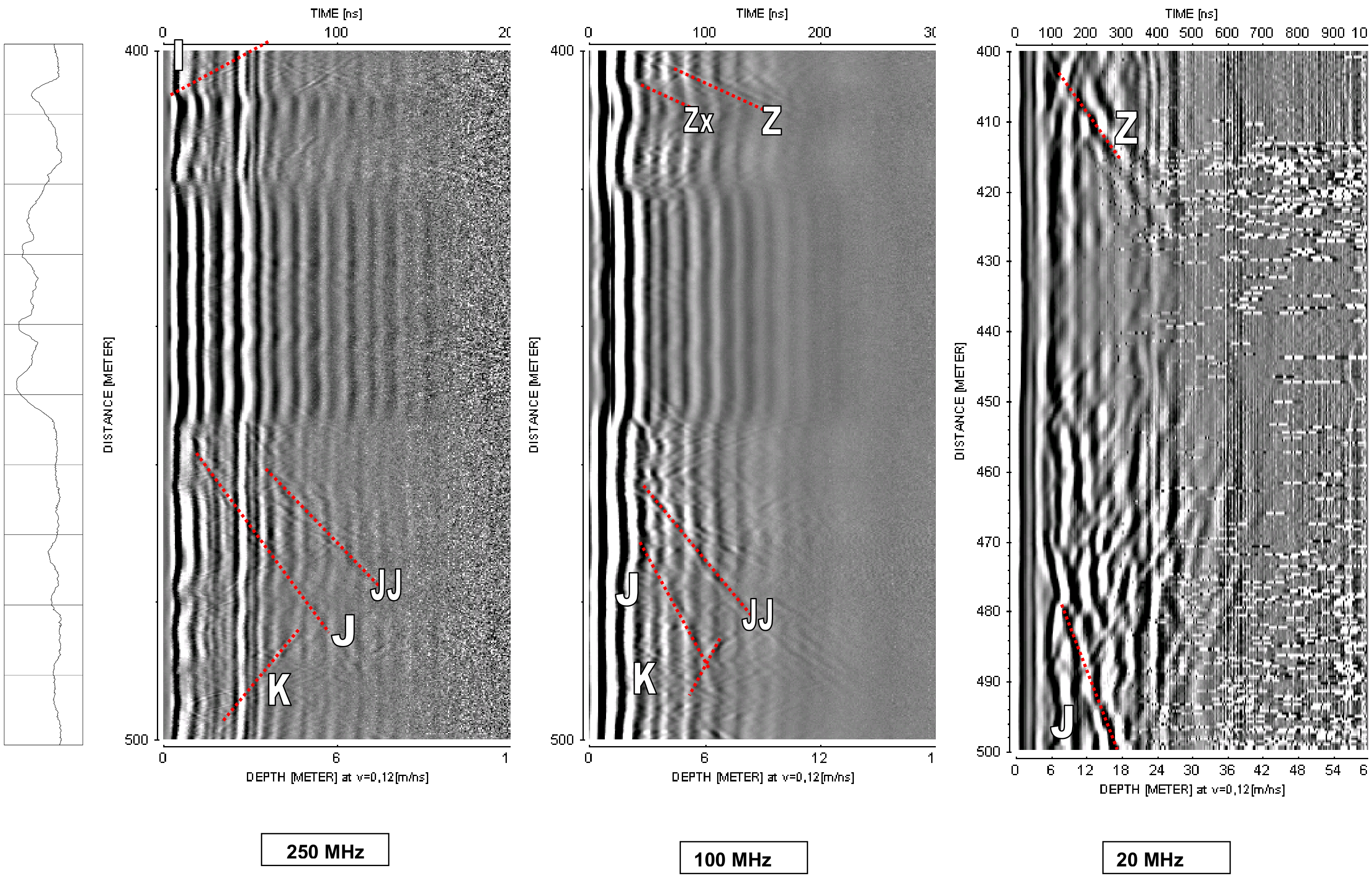
250 MHz

100 MHz

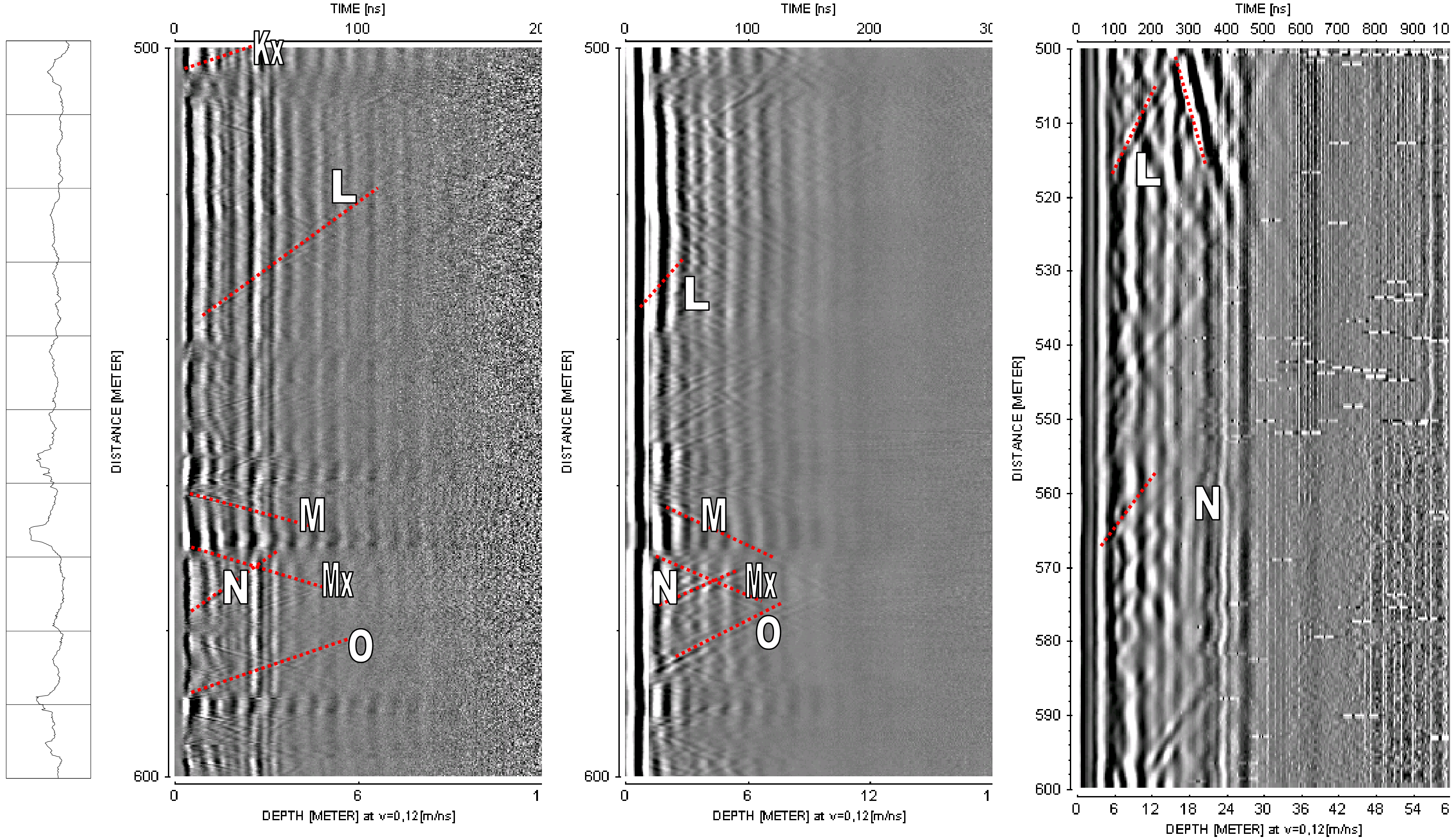
20 MHz


OSKARSHAMN KSH01A with interpretation
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,12[m/ns]
2
3
4
5
G
H
HH
250 MHz
100 MHz
20 MHz

OSKARSHAMN KSH01A with interpretation

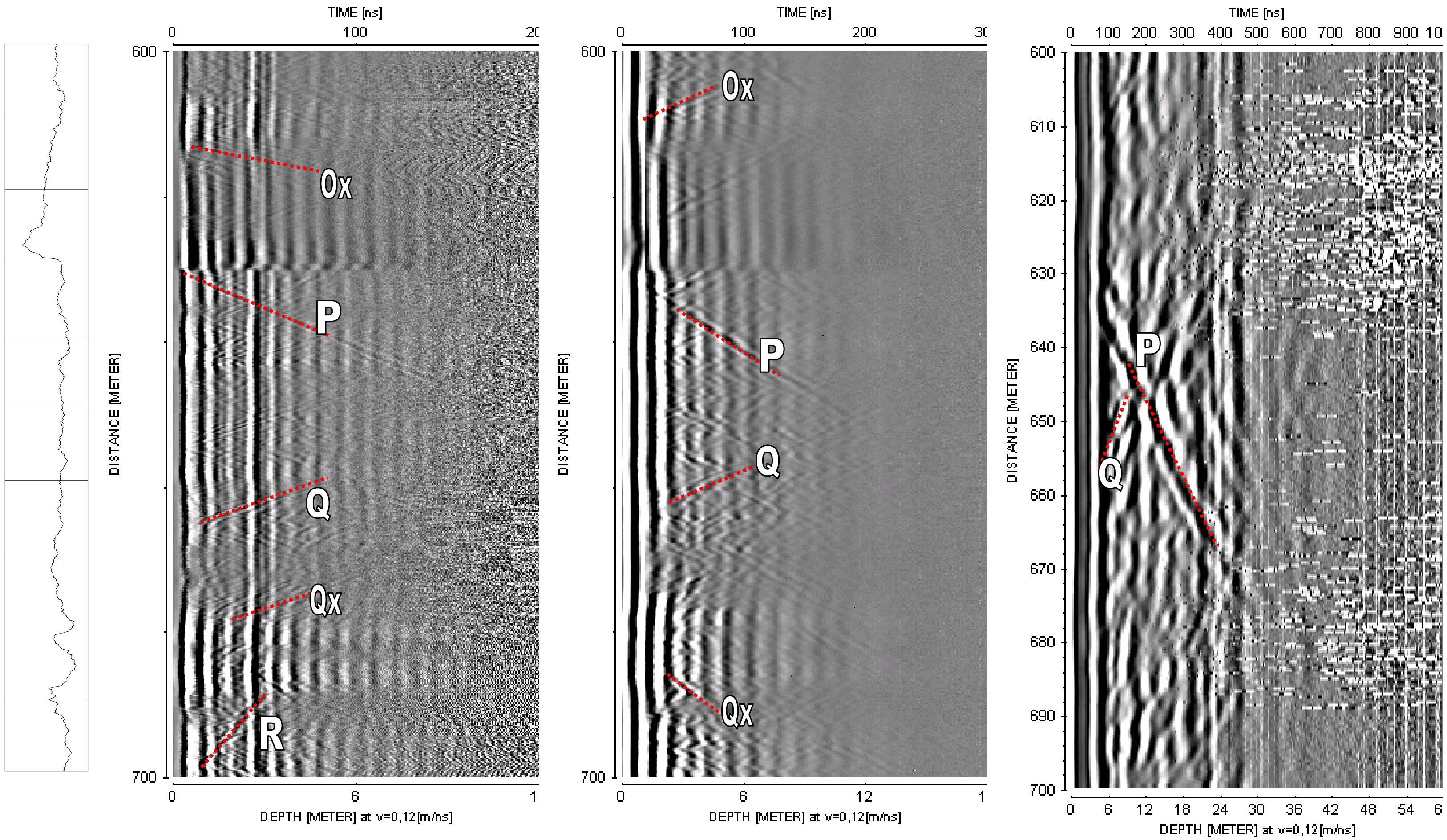


OSKARSHAMN KSH01A with interpretation



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

OSKARSHAMN KSH01A with intepretation

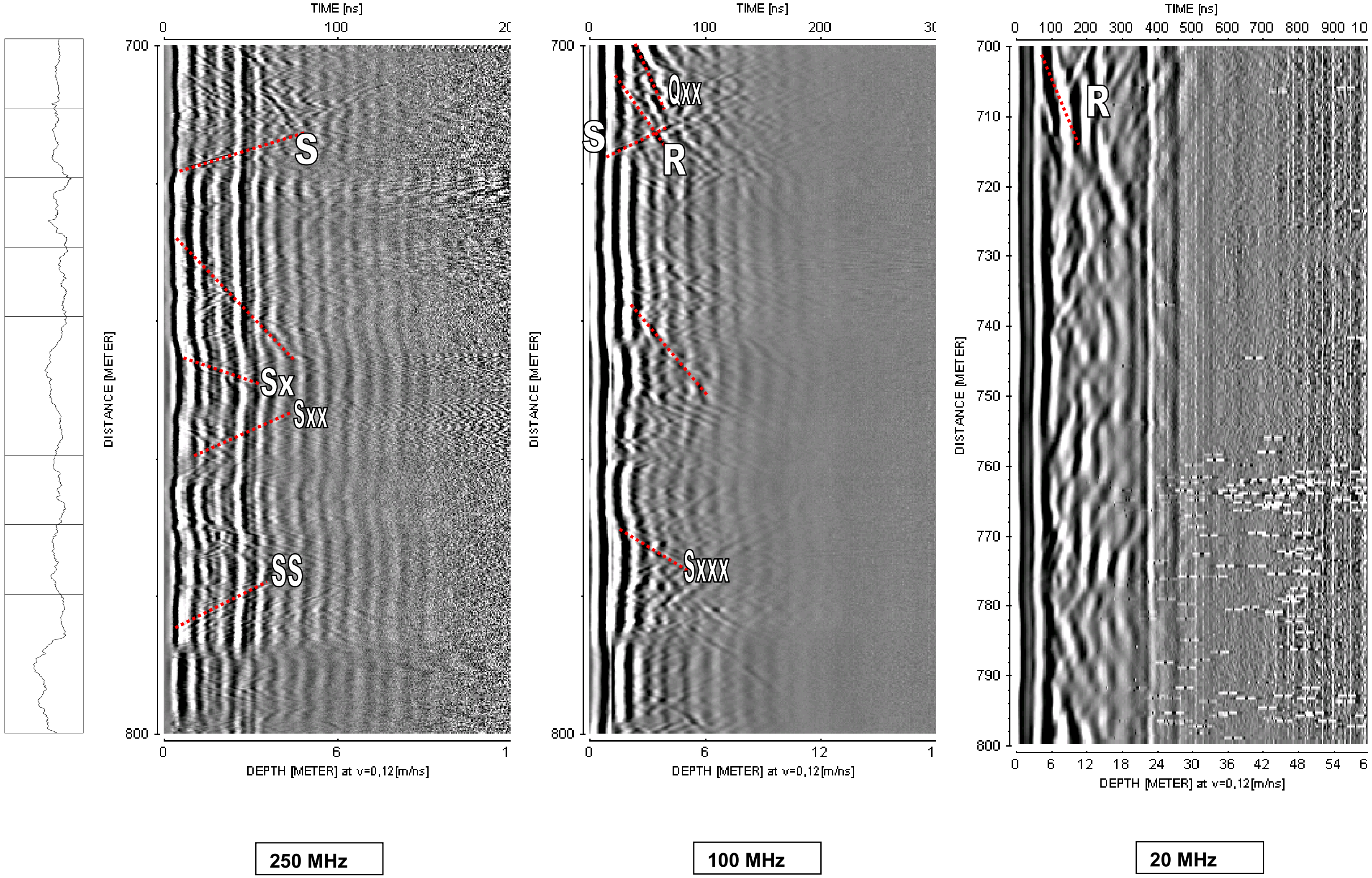


250 MHz

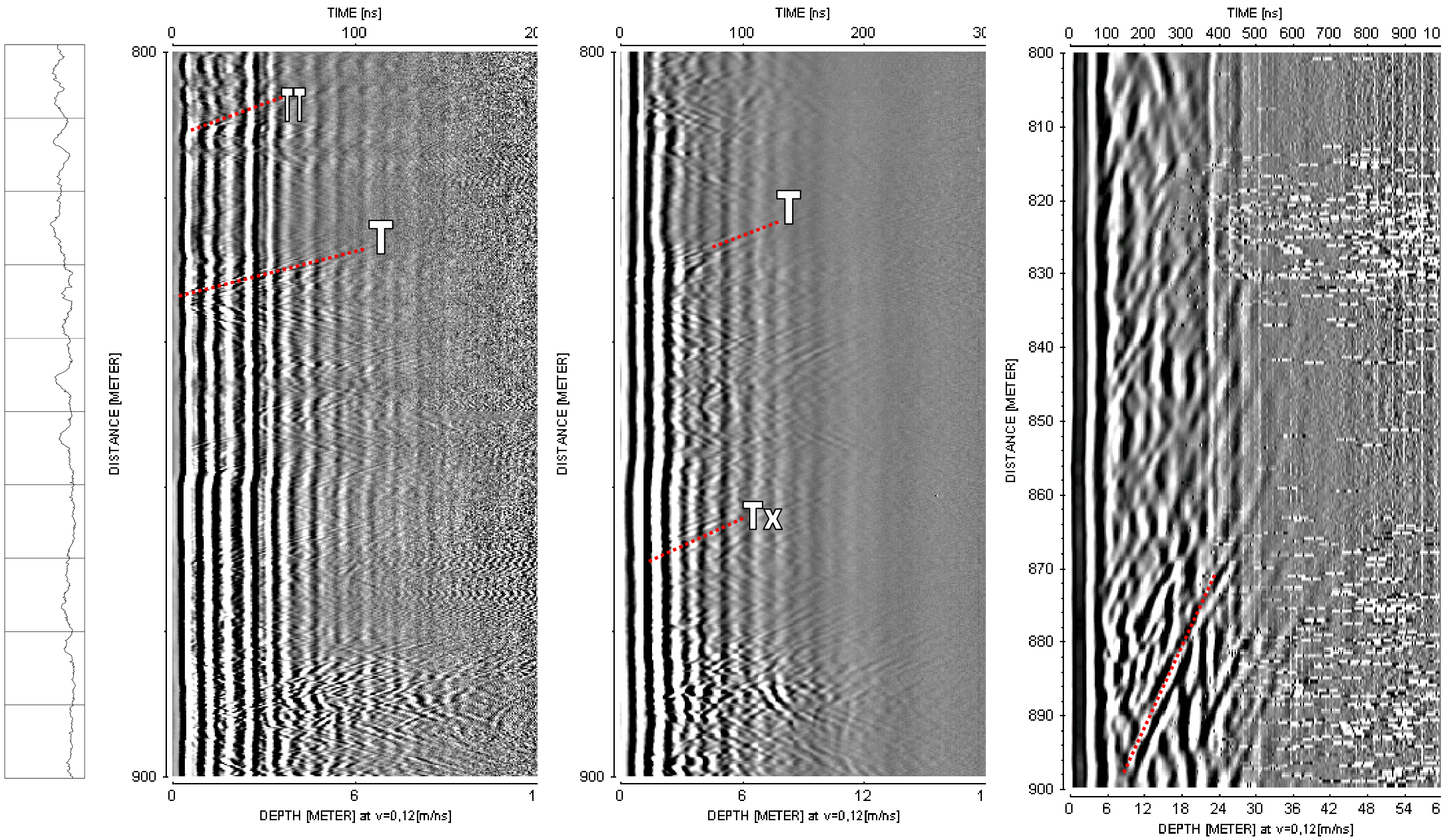
100 MHz

20 MHz

OSKARSHAMN KSH01A with interpretation



OSKARSHAMN KSH01A with interpretation

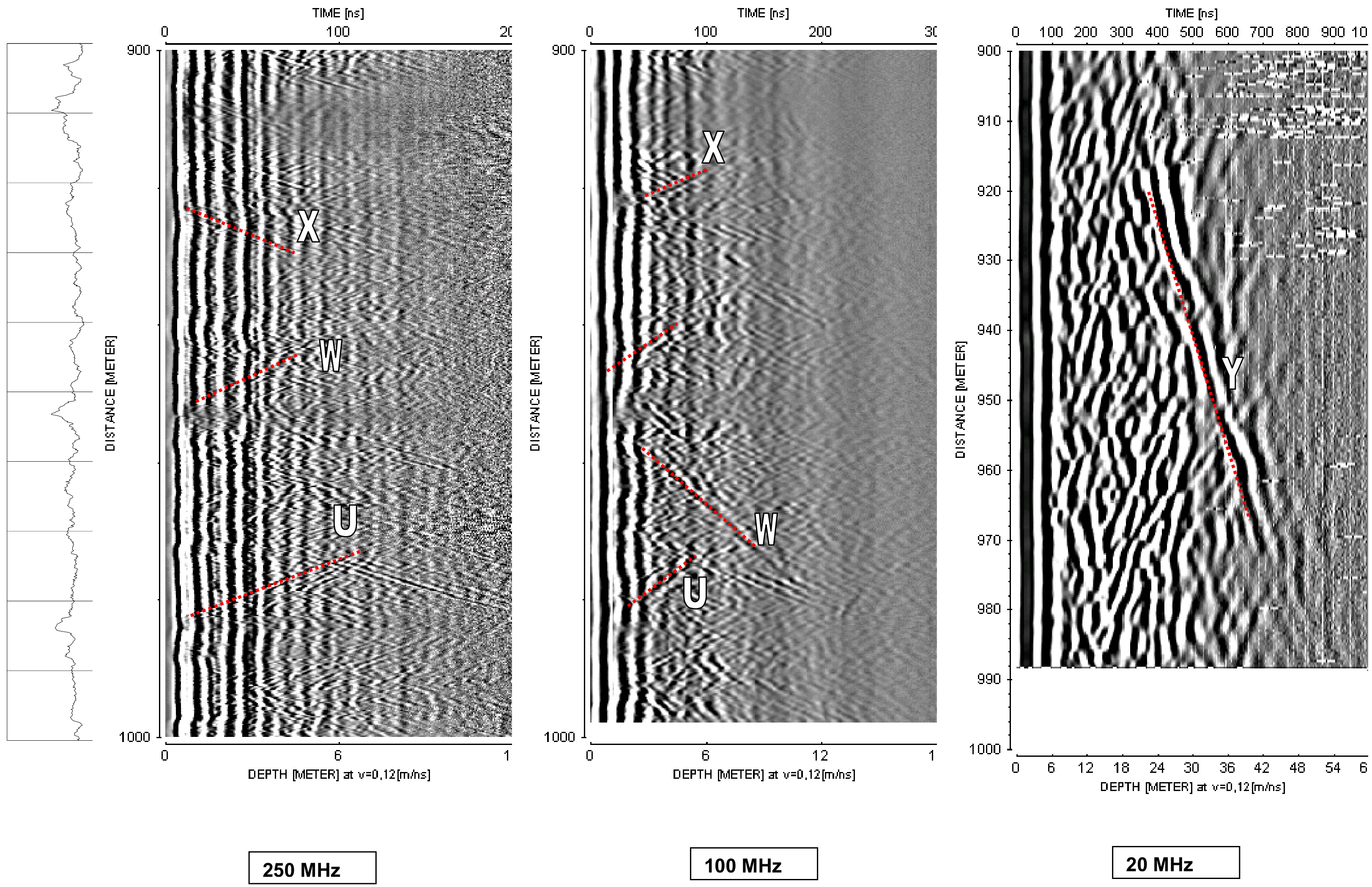


250 MHz

100 MHz

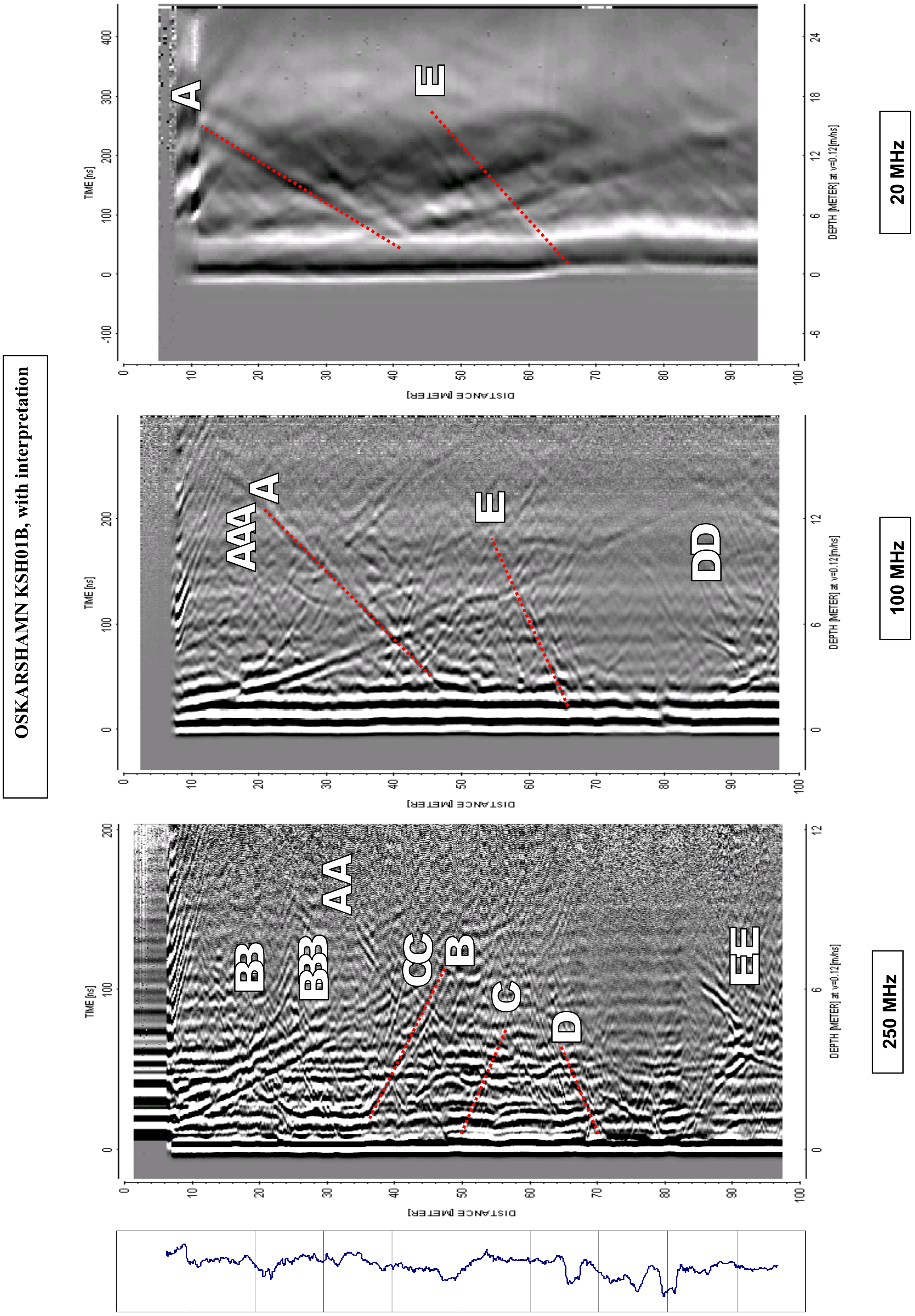
20 MHz

OSKARSHAMN KSH01A with interpretation



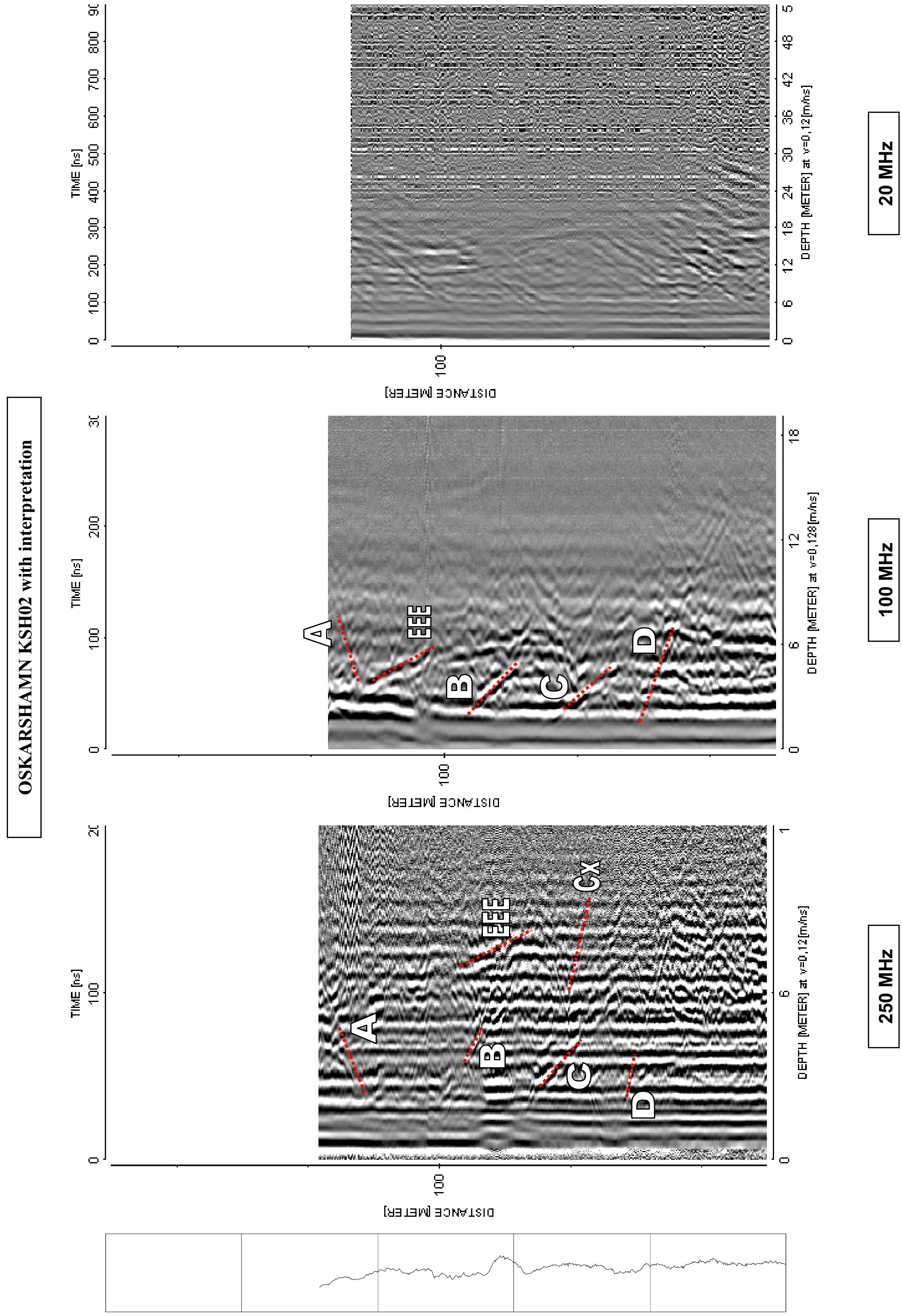
Appendix 2

Radar logging in KSH01B with dipole antennas 250, 100 and 20 MHz

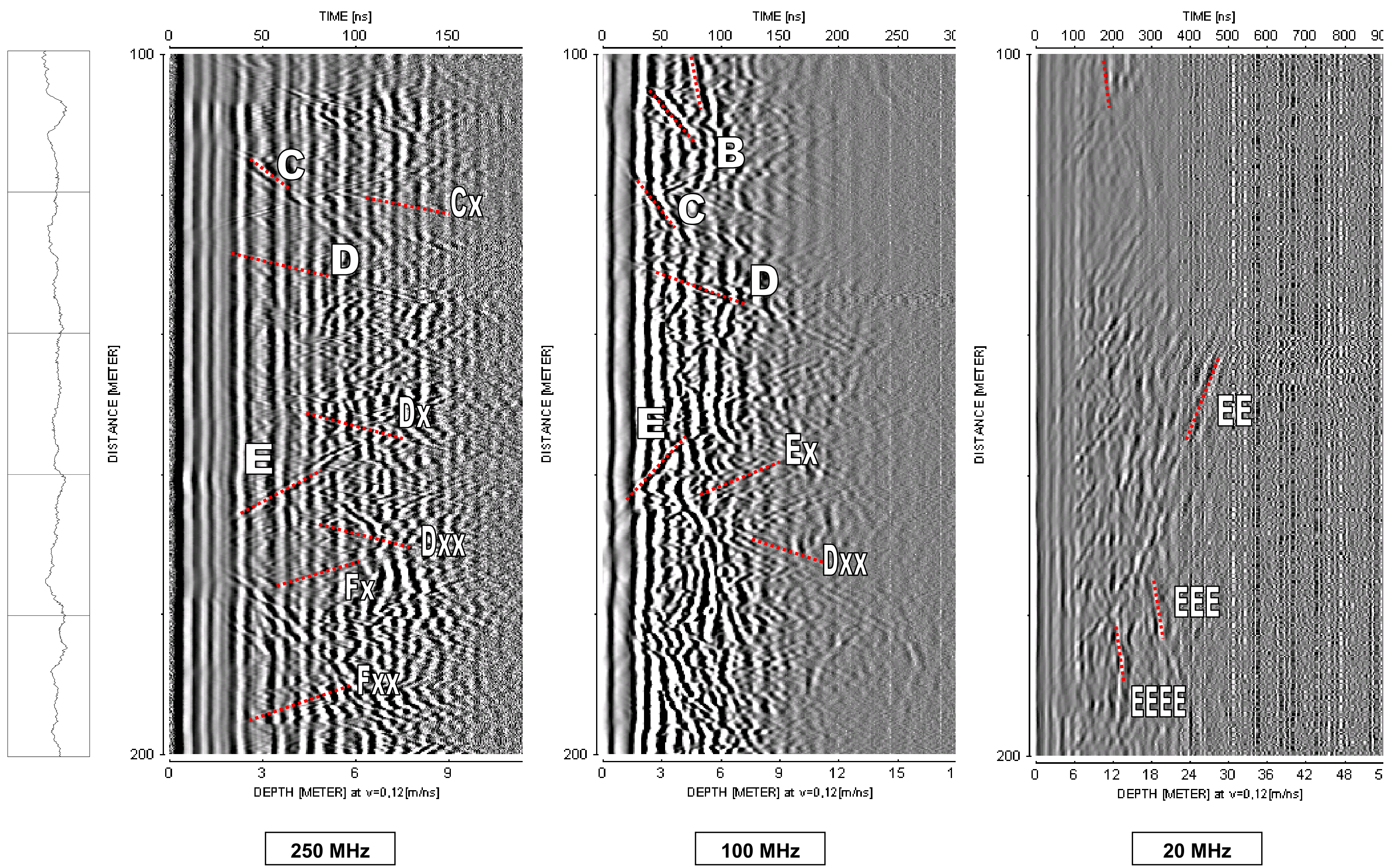


Appendix 3

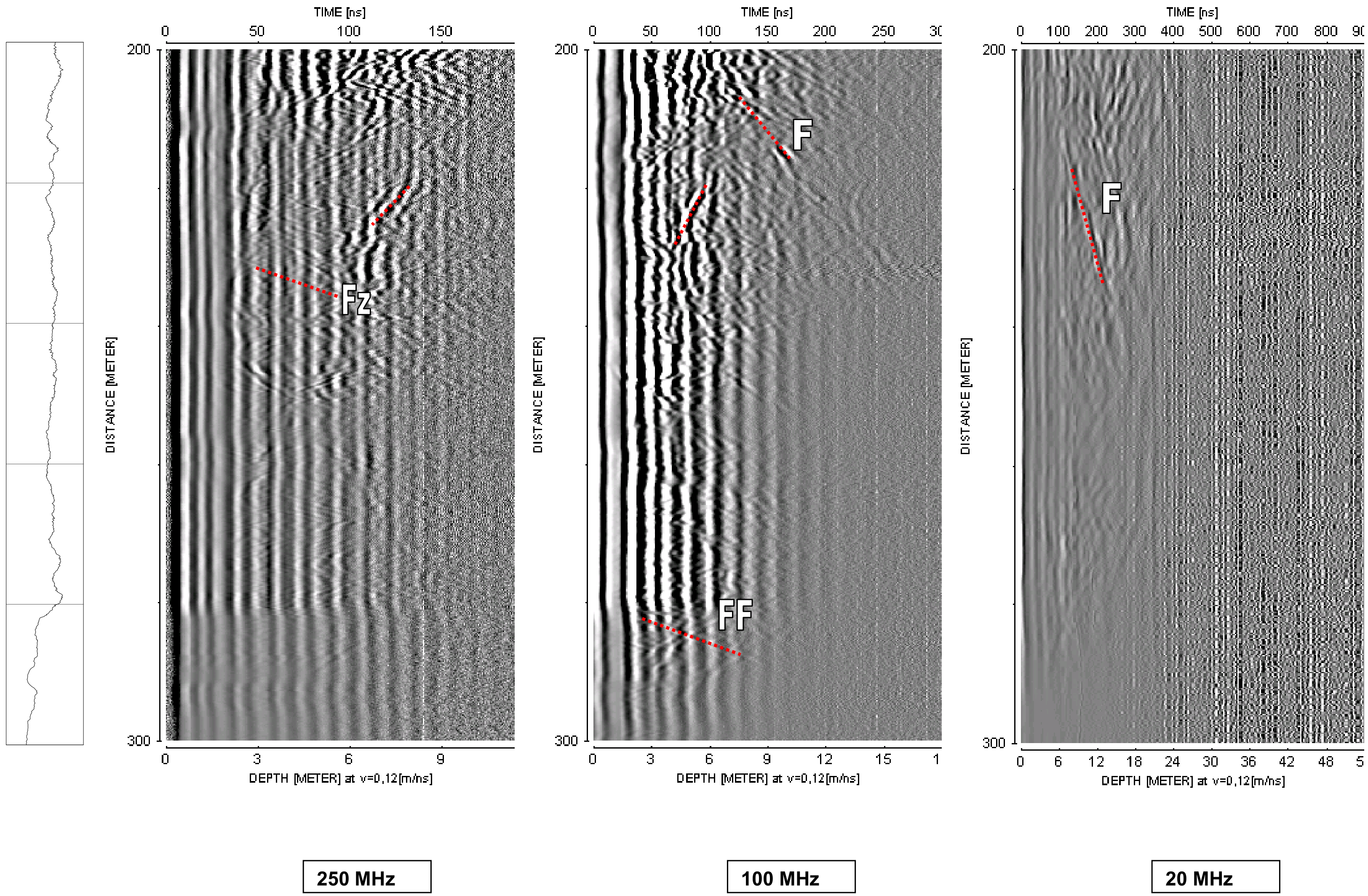
Radar logging in KSH02 with dipole antennas 250, 100 and 20 MHz



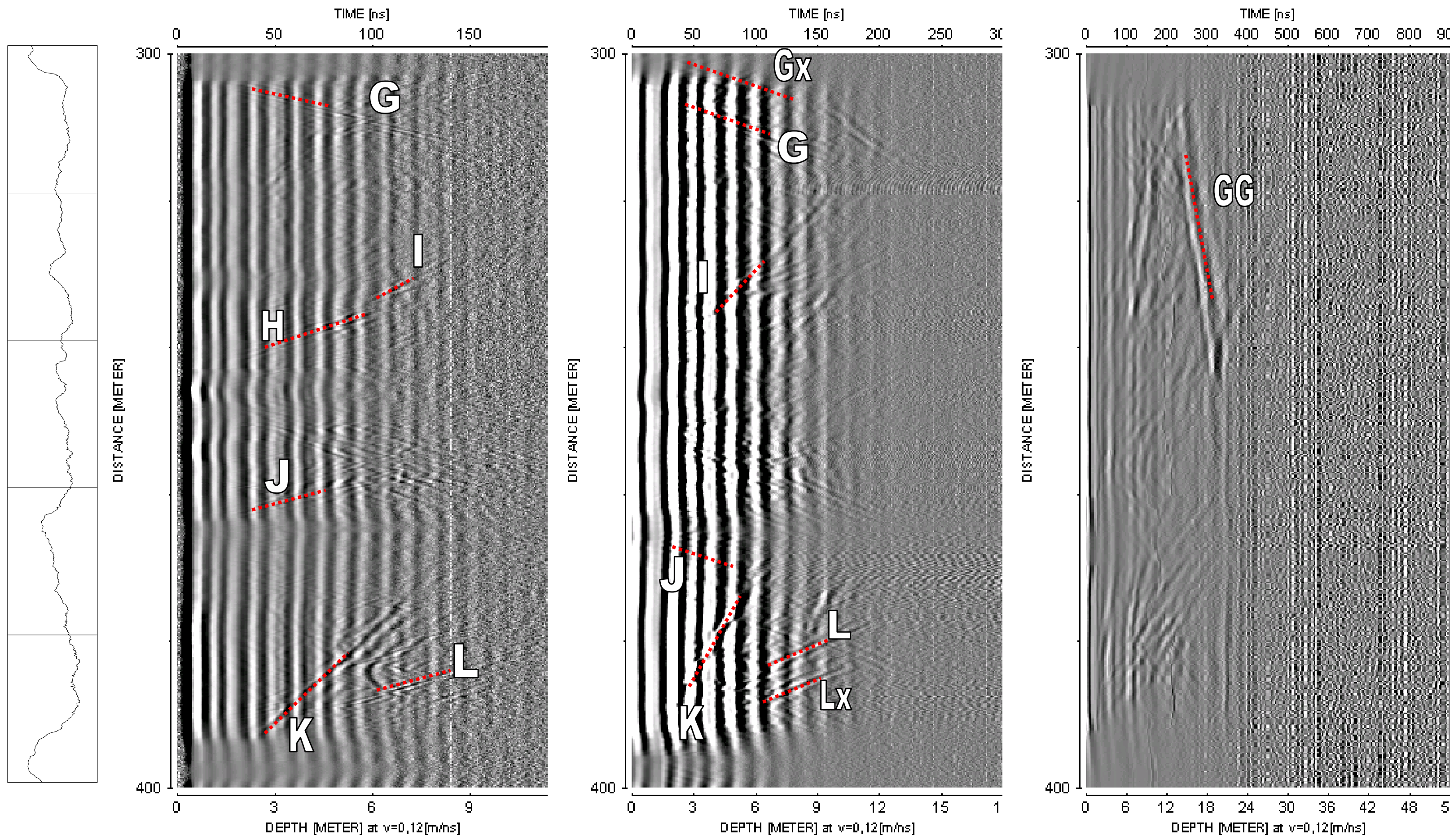
OSKARSHAMN KSH02 with interpretation



OSKARSHAMN KSH02 with interpretation



OSKARSHAMN KSH02 with interpretation

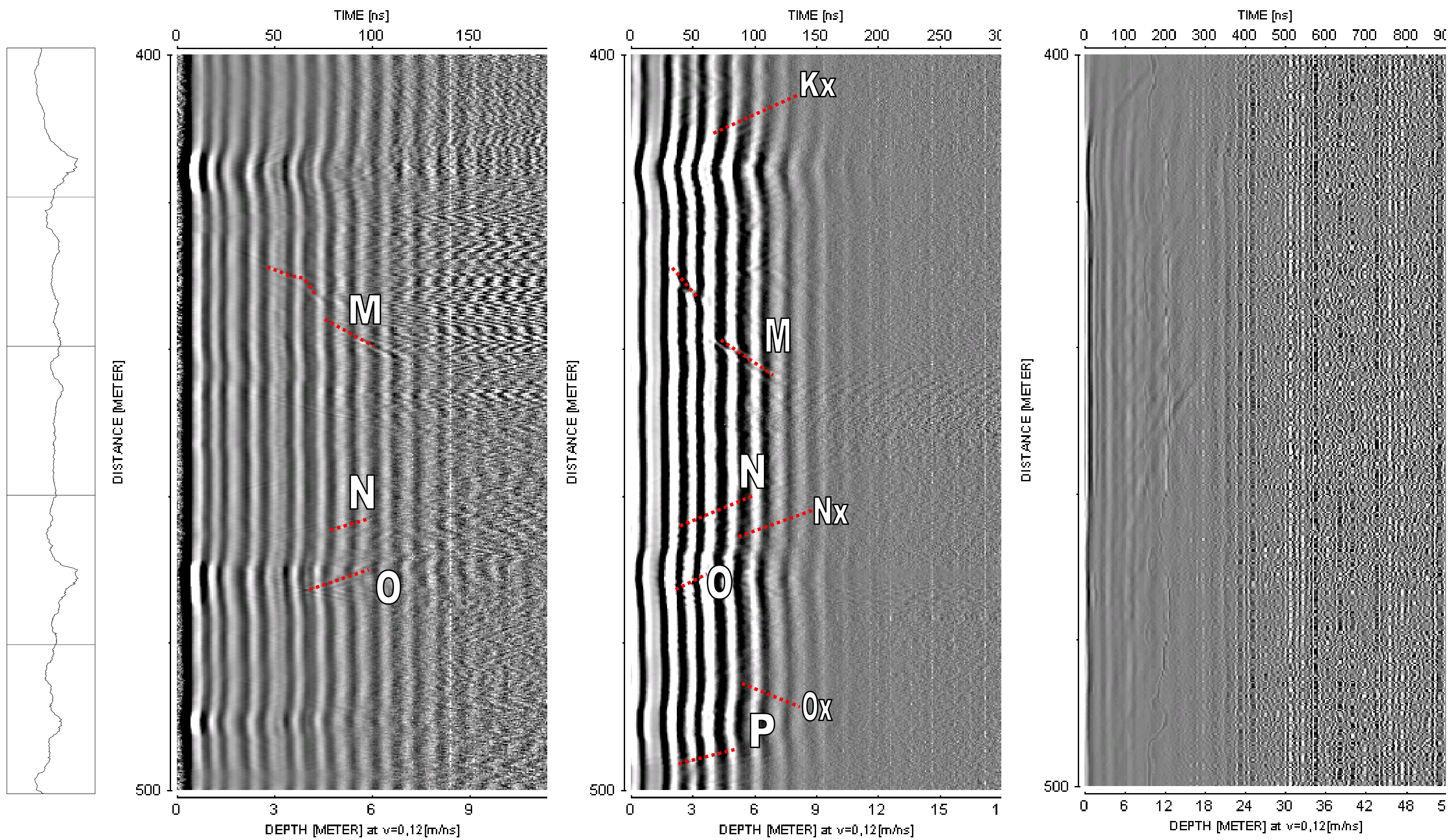


250 MHz

100 MHz

20 MHz

OSKARSHAMN KSH02 with interpretation

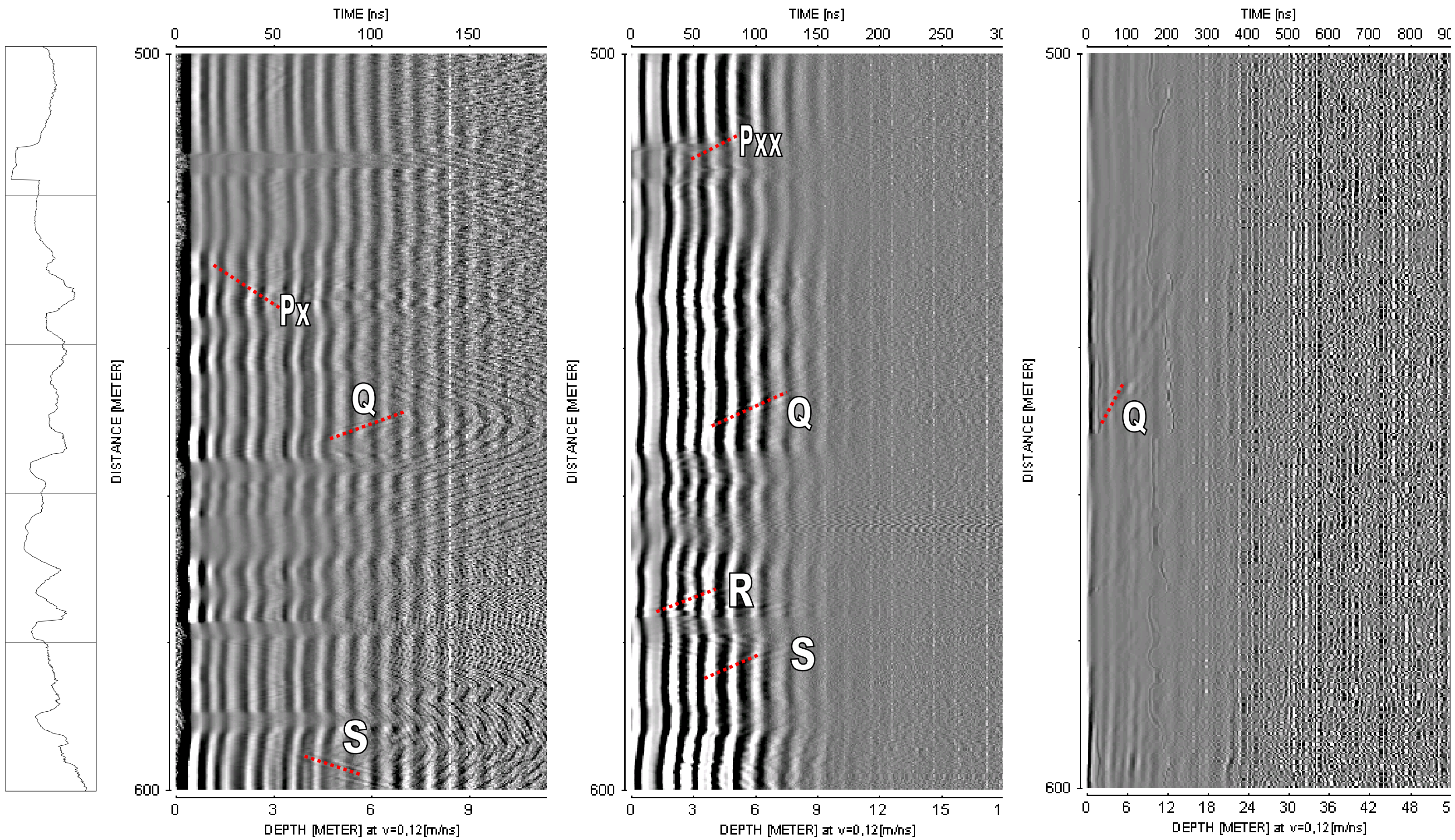


250 MHz

100 MHz

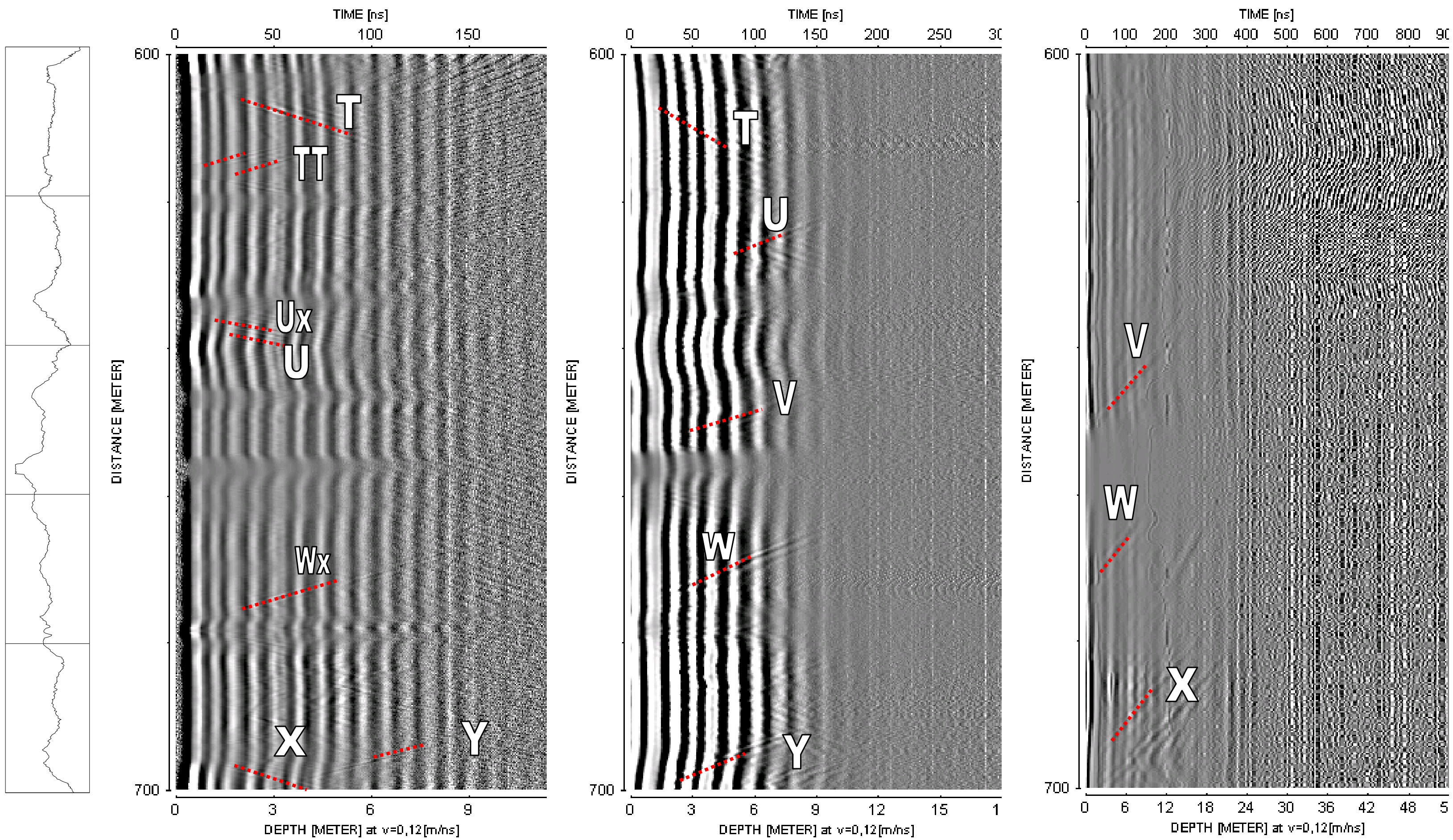
20 MHz

OSKARSHAMN KSH02 with interpretation



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

OSKARSHAMN KSH02 with interpretation

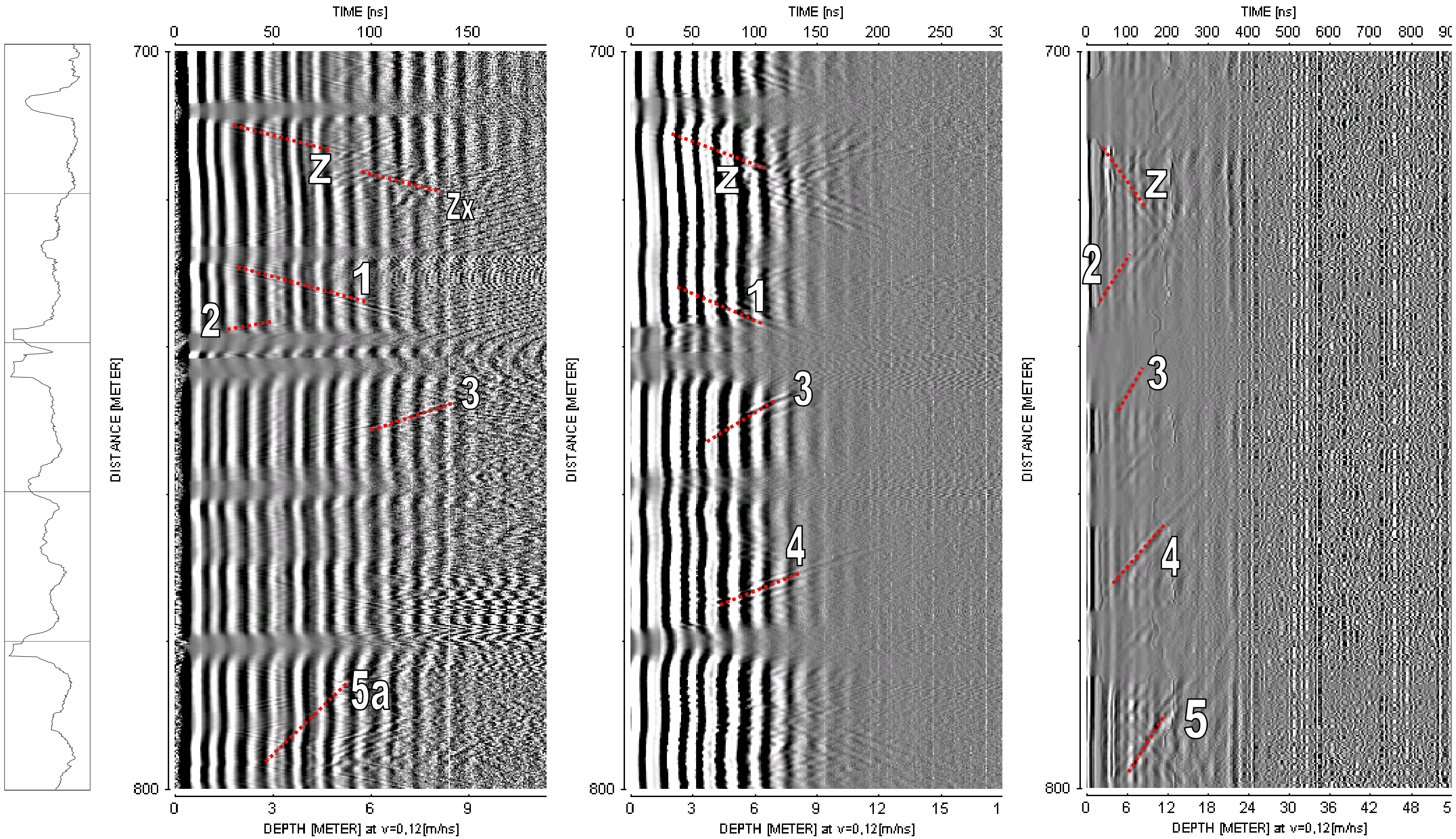


250 MHz

100 MHz

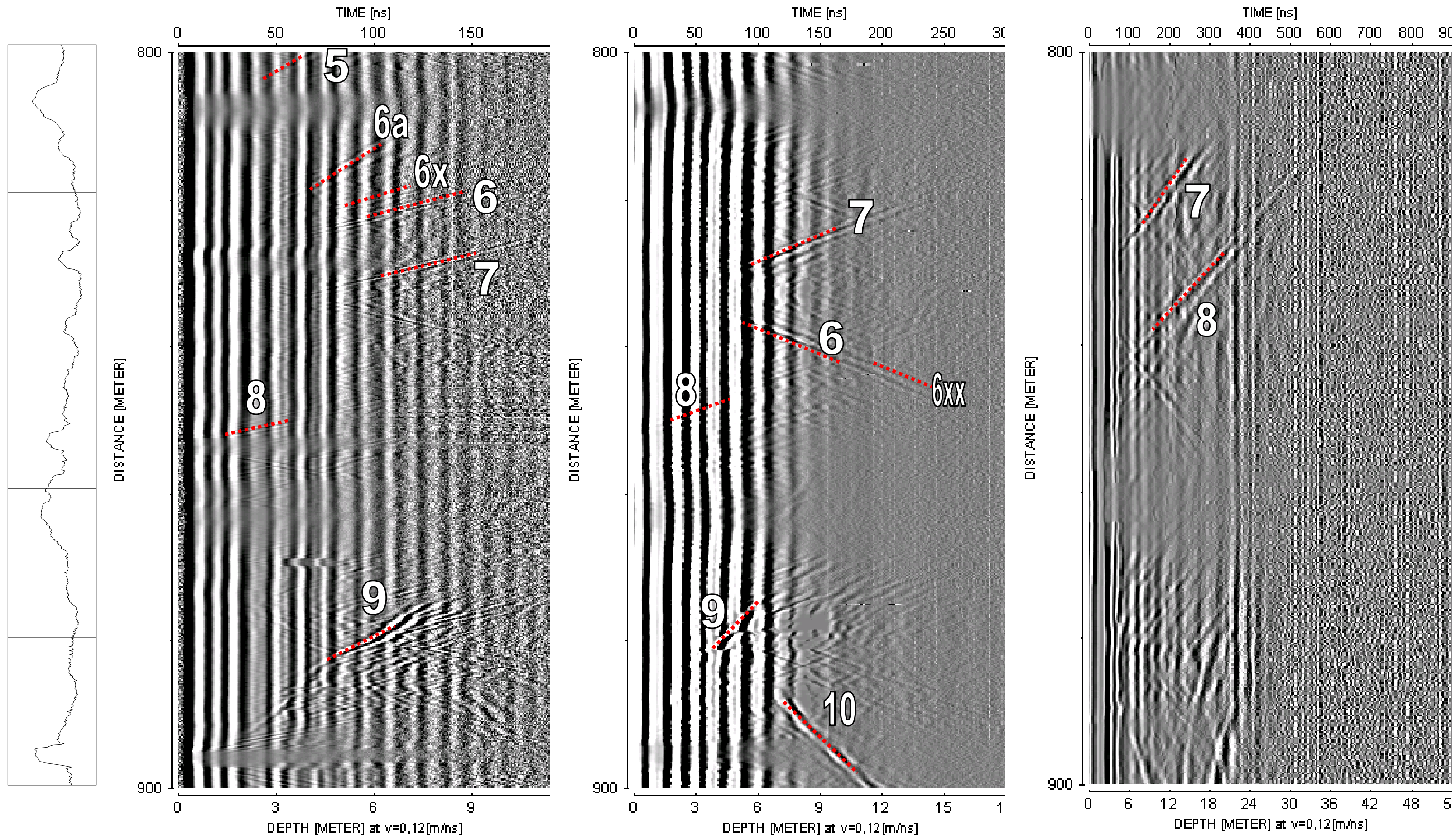
20 MHz

OSKARSHAMN KSH02 with interpretation



250 MHz 100 MHz 20 MHz

OSKARSHAMN KSH02 with interpretation

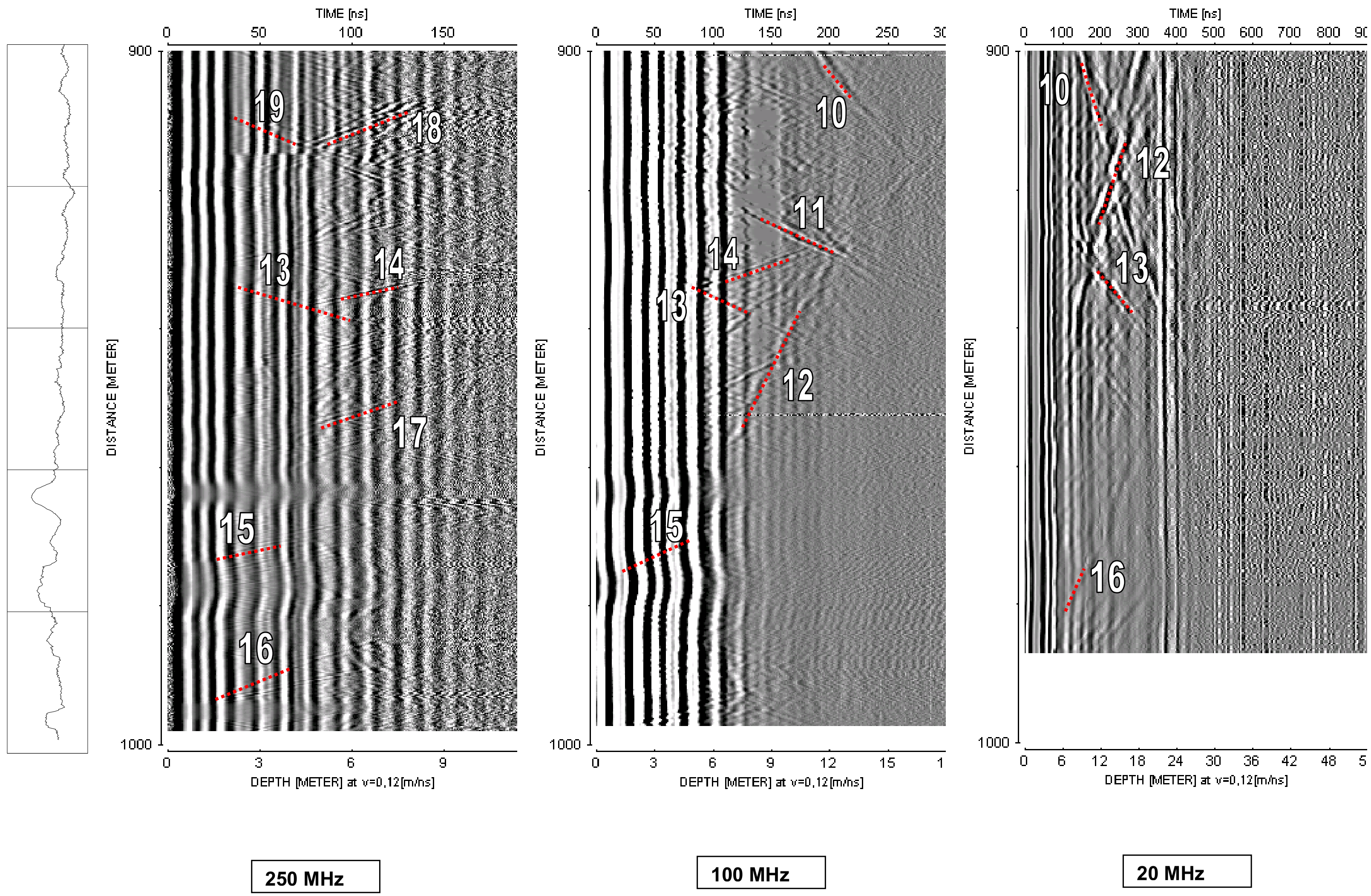


250 MHz

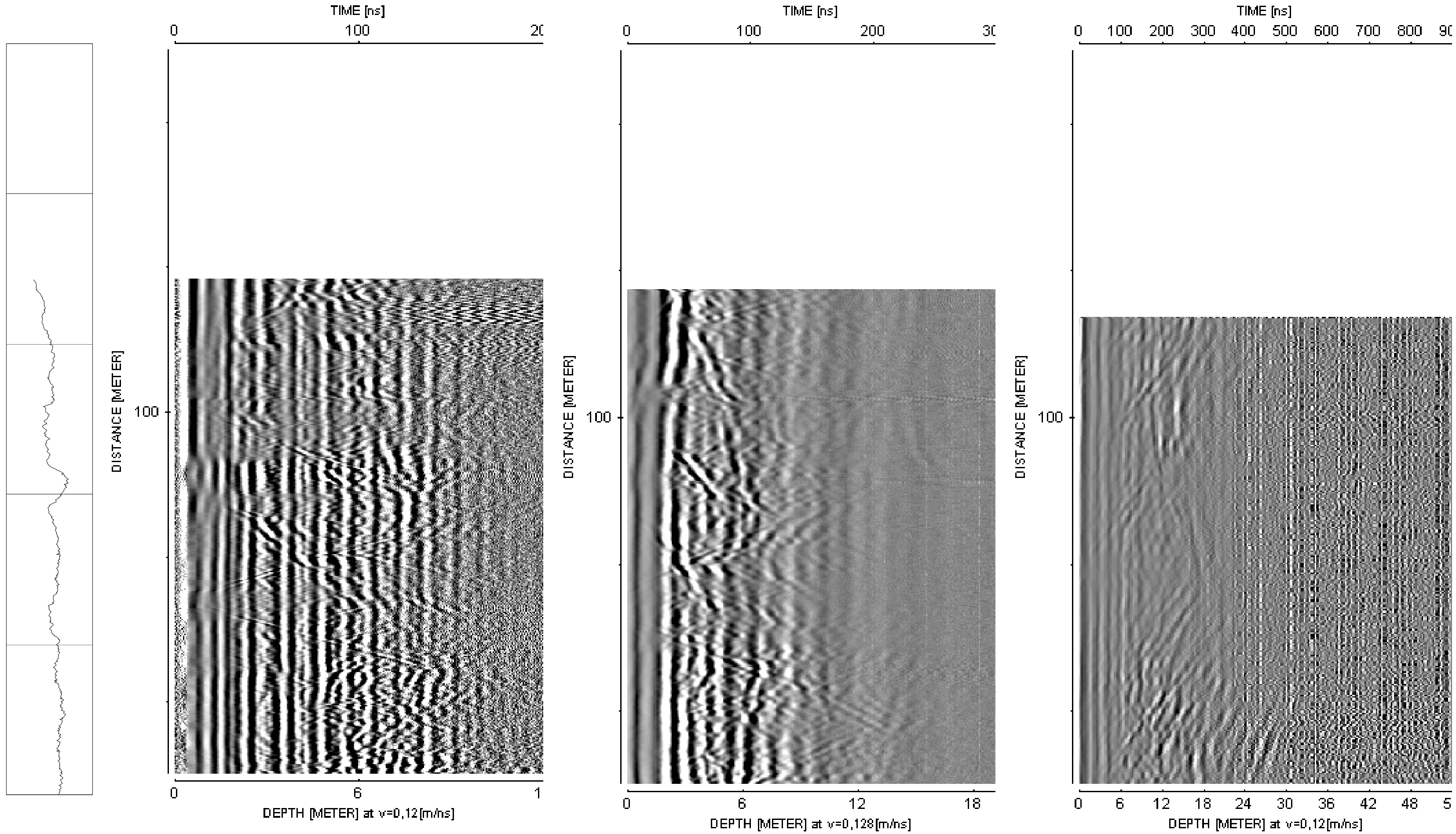
100 MHz

20 MHz

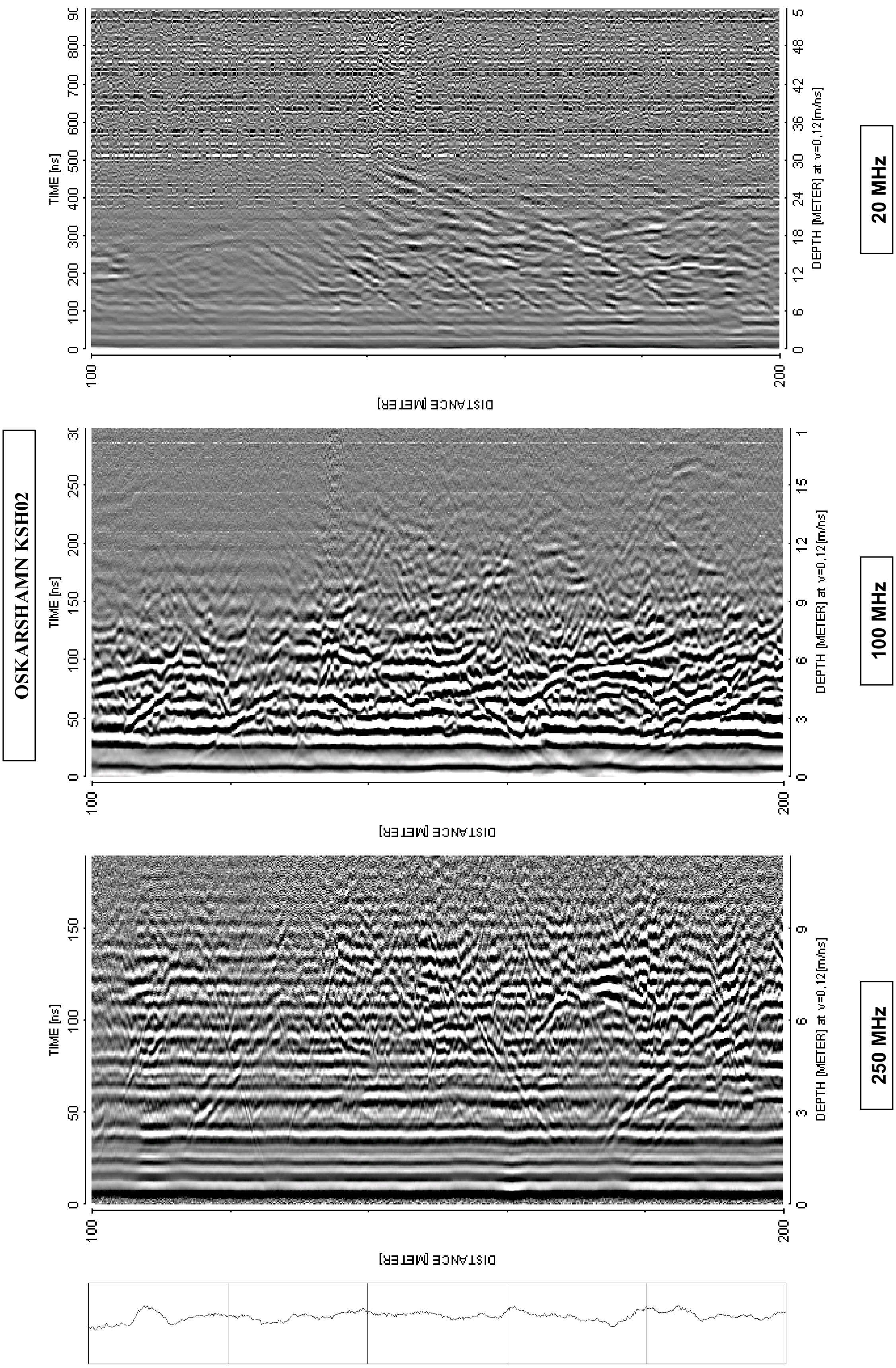
OSKARSHAMN KSH02 with interpretation

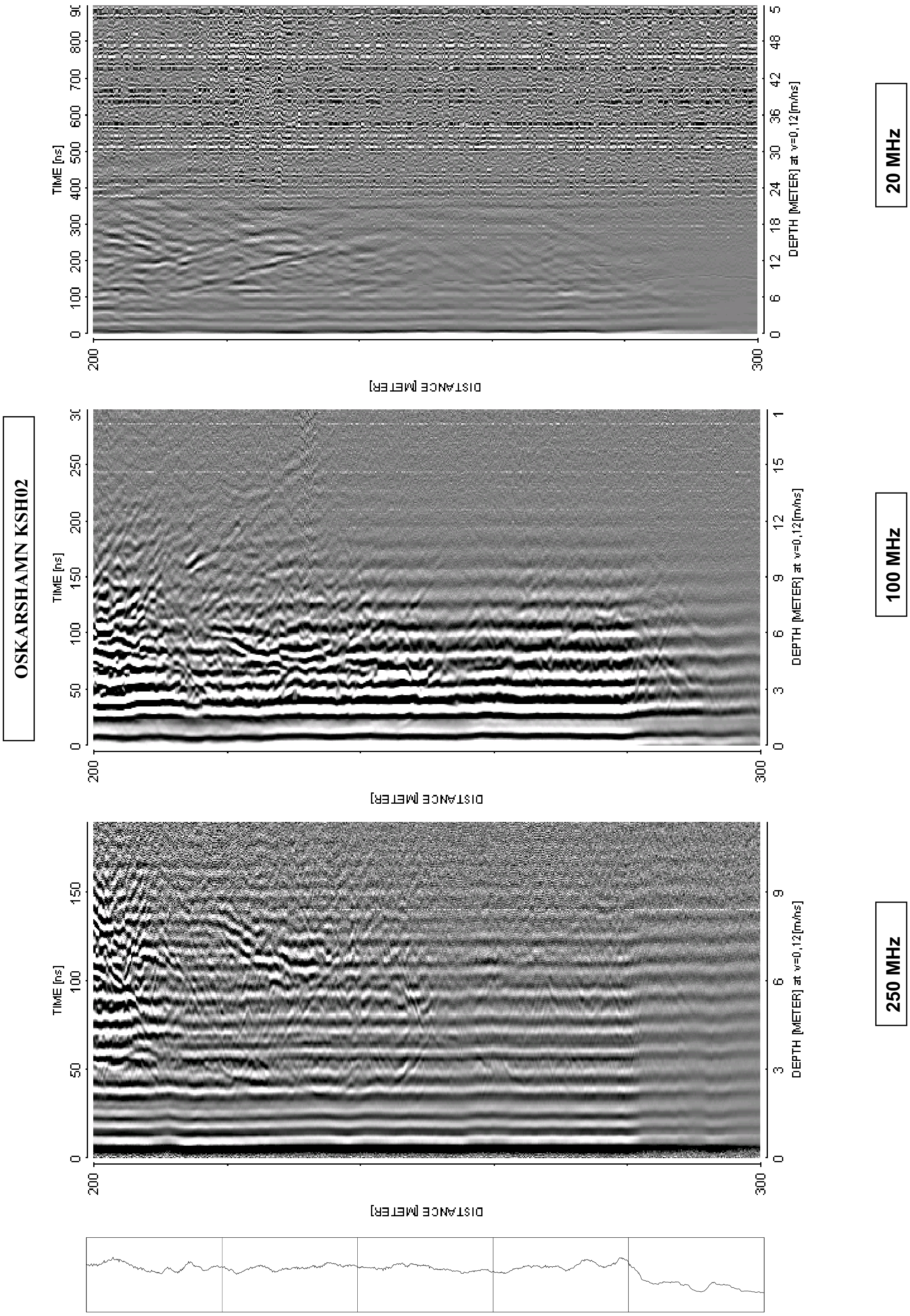


OSKARSHAMN KSH02

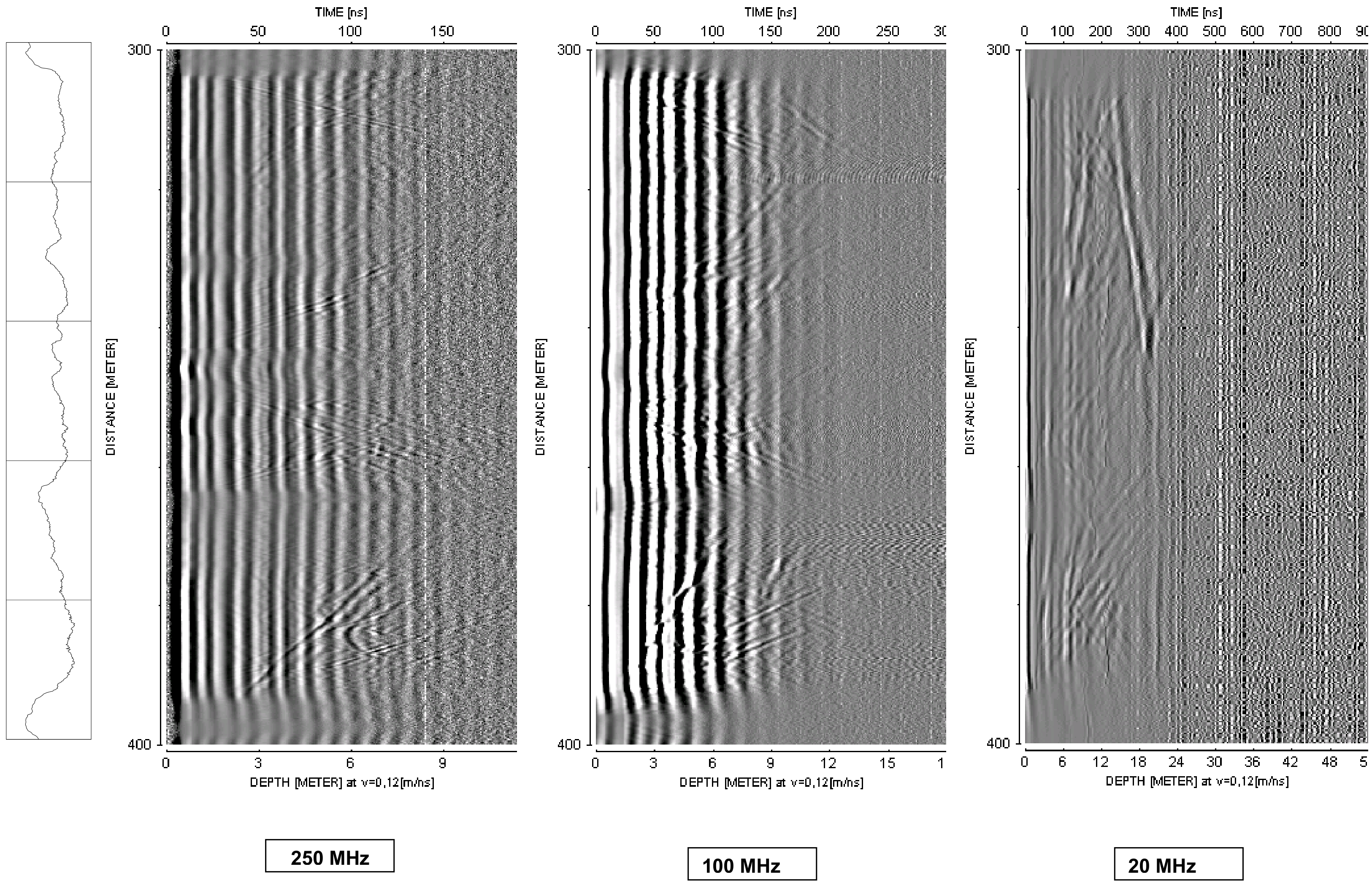


250 MHz **100 MHz** **20 MHz**

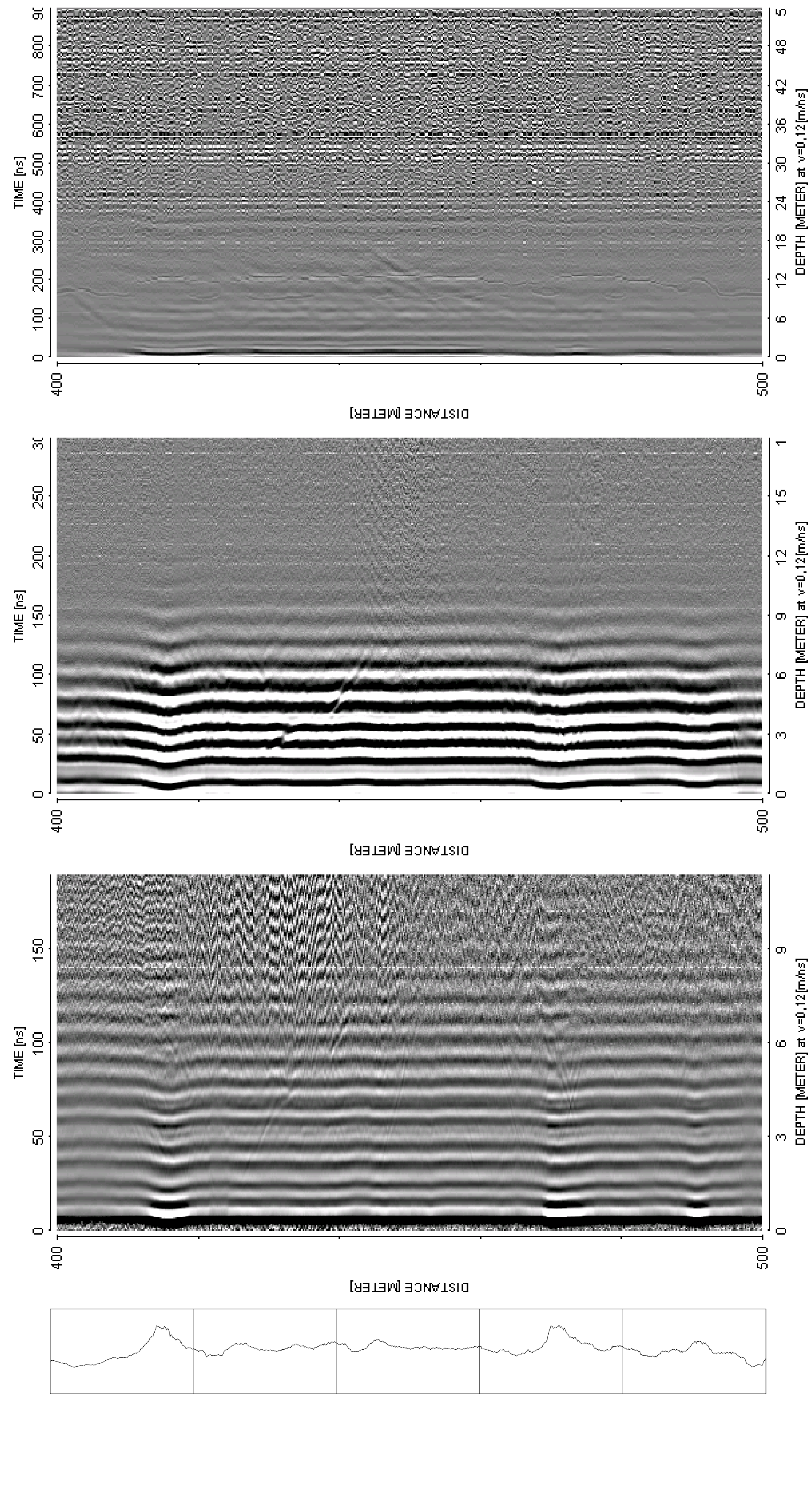

OSKARSHAMN KSH02
TIME [ns]
DEPTH [METER] at v=0,12 [m/ns]
DISTANCE [METER]
20 MHz
100 MHz
250 MHz


OSKARSHAMN KSH02
20 MHz
100 MHz
250 MHz
TIME [ns]
DEPTH [METER] at v=0,12[m/ns]
DISTANCE [METER]

OSKARSHAMN KSH02



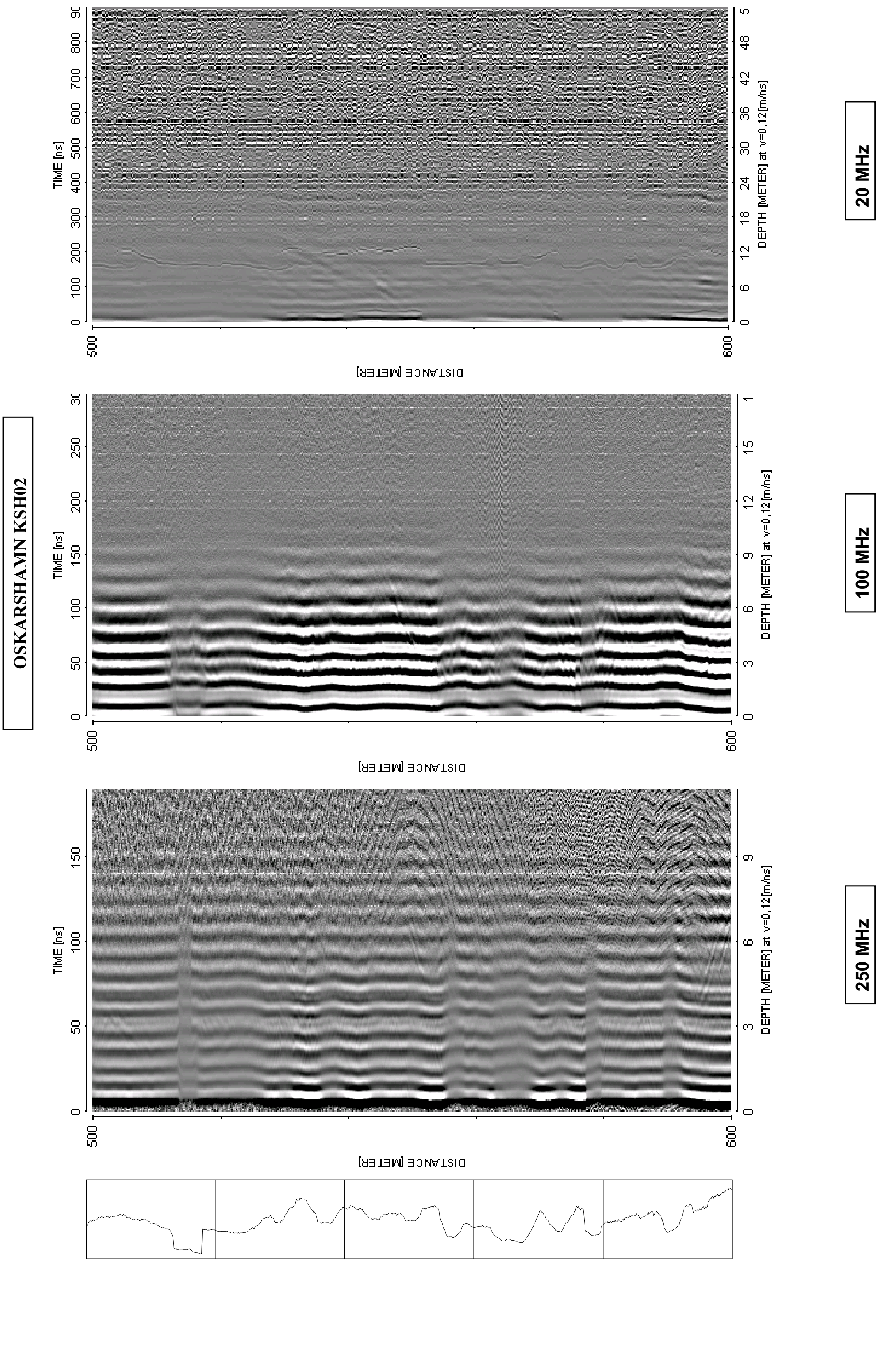
OSKARSHAMN KSH02



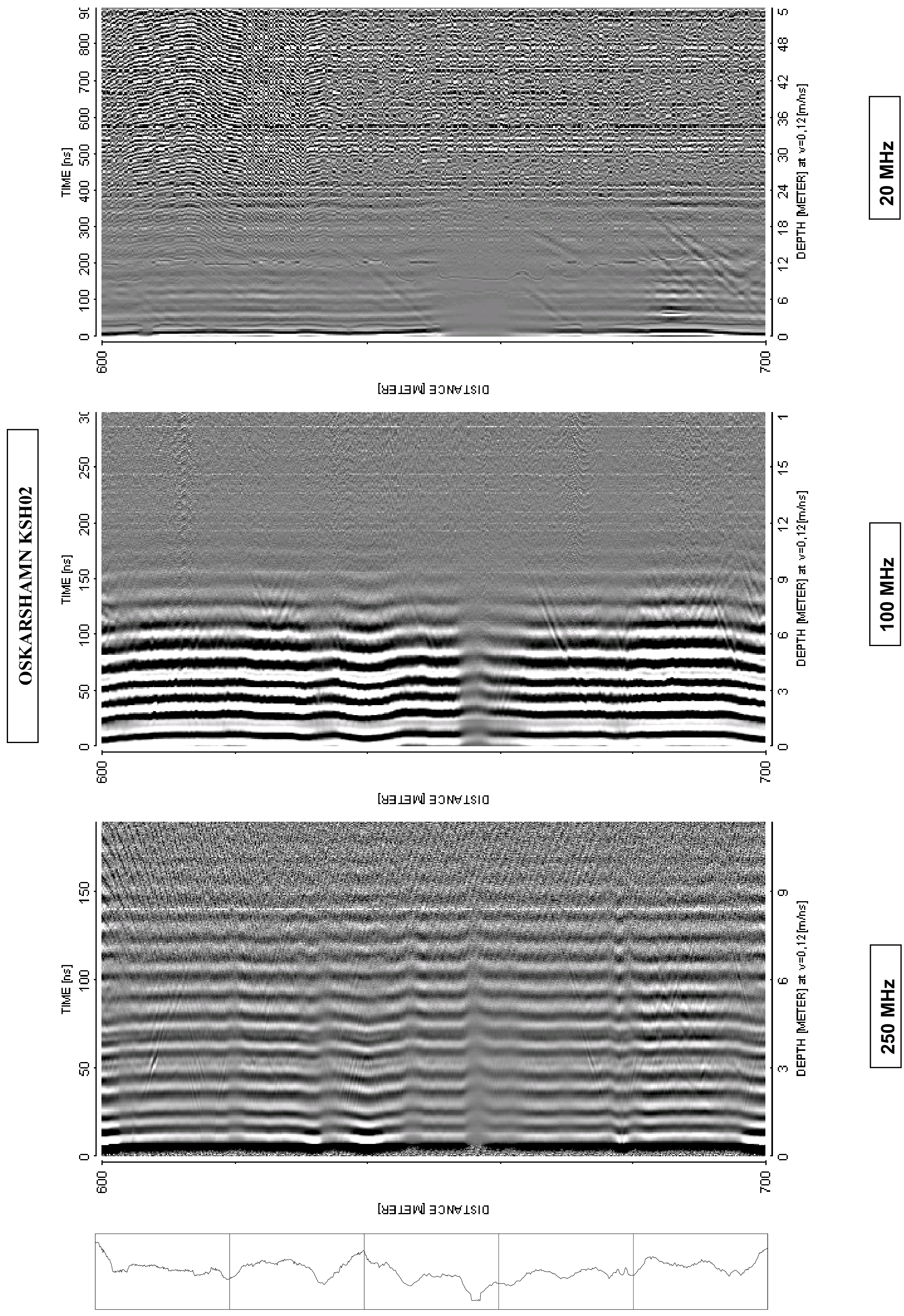
20 MHz

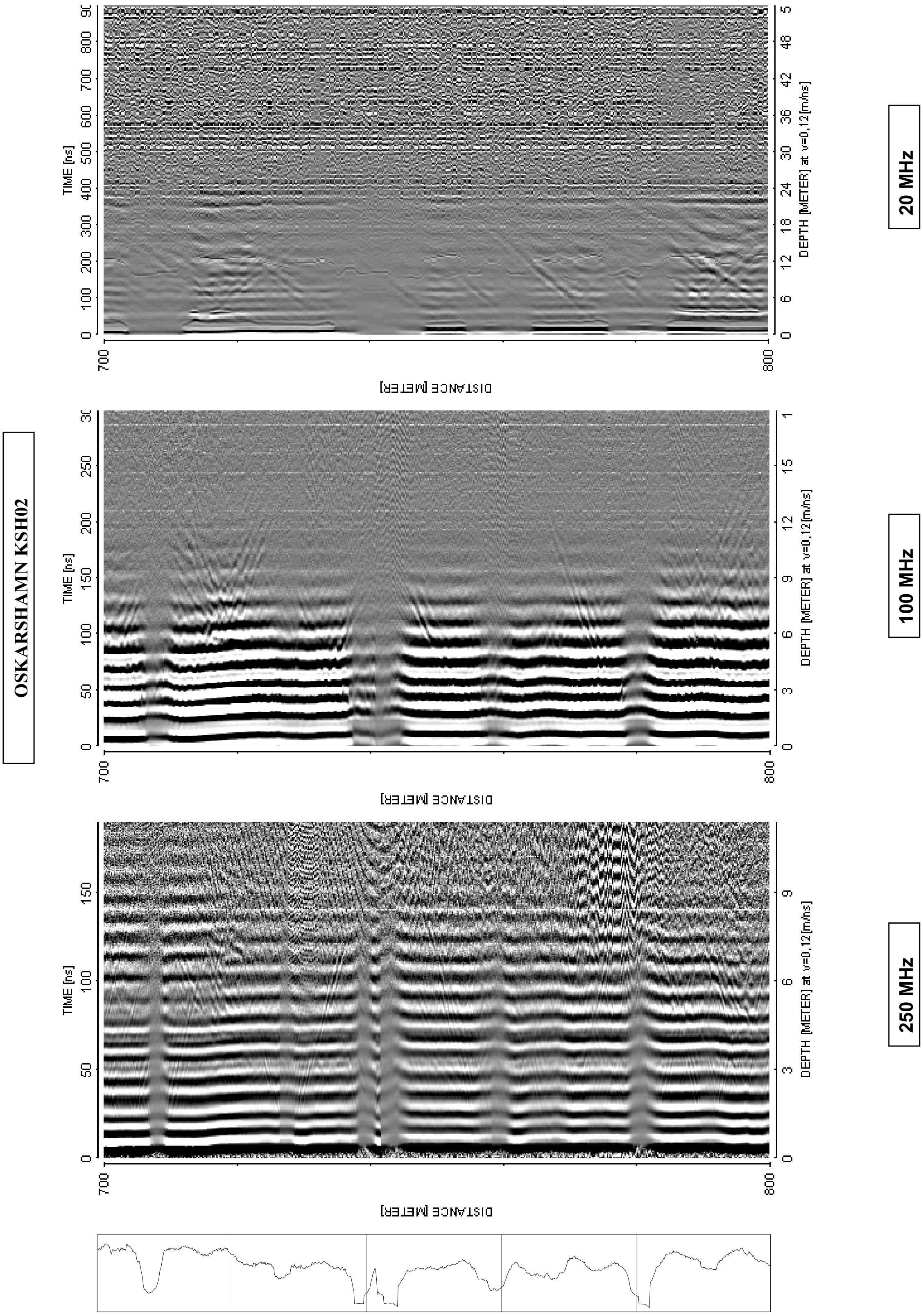
100 MHz

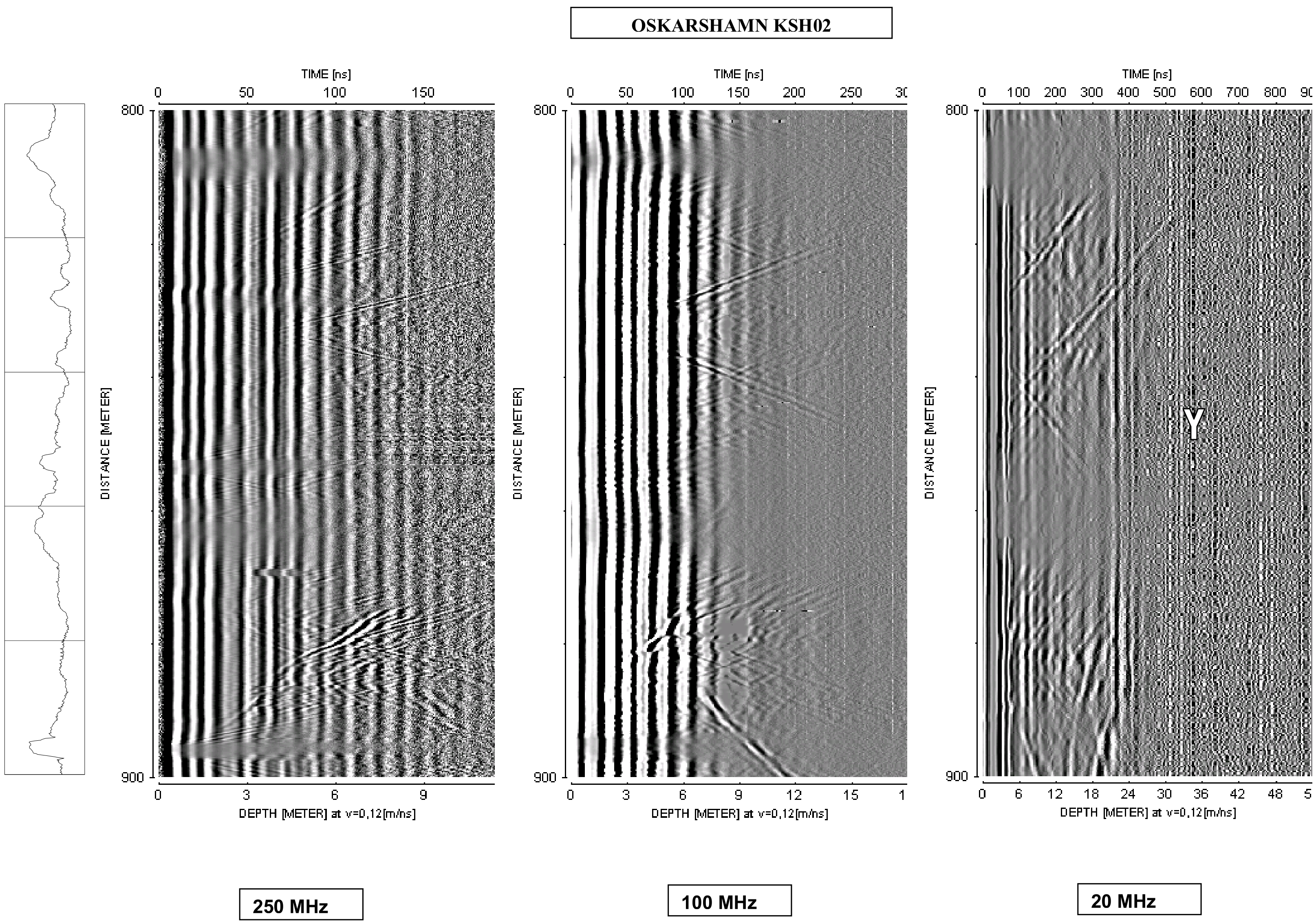
250 MHz



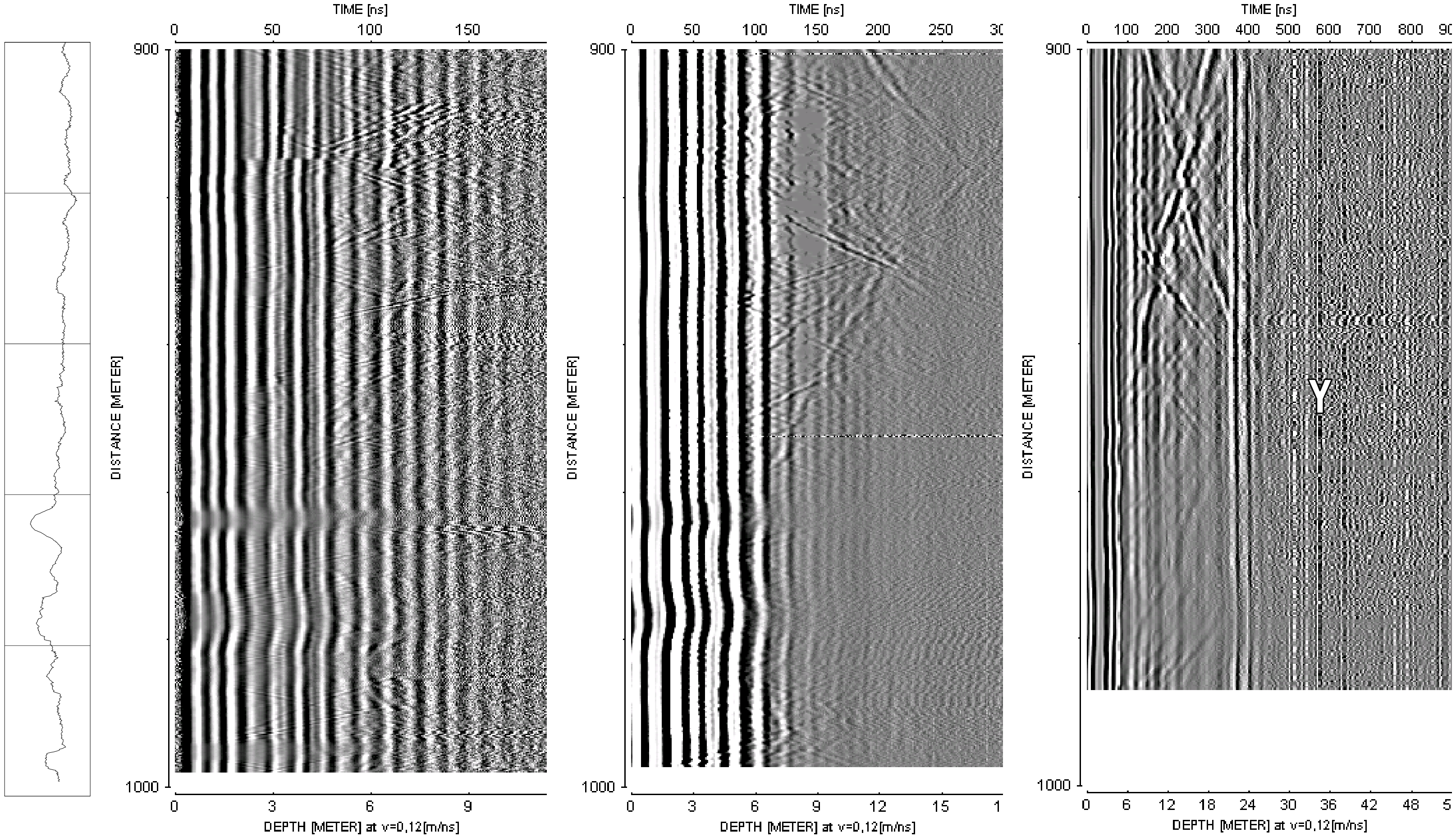
OSKARSHAMN KSH02
20 MHz
100 MHz
250 MHz
TIME [ns]
DEPTH [METER] at v=0,12 [m/ns]
DISTANCE [METER]
500
600


OSKARSHAMN KSH02
20 MHz
100 MHz
250 MHz
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,12[m/ns]


OSKARSHAMN KSH02
20 MHz
100 MHz
250 MHz
TIME [ns]
DEPTH [METER] at v=0,12[m/ns]
DISTANCE [METER]
700
800


OSKARSHAMN KSH02
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,12[m/ns]
250 MHz
100 MHz
20 MHz
Y

OSKARSHAMN KSH02



250 MHz

100 MHz

20 MHz