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Revised April 2006

Oskarshamn site investigation

RAMAC logging in boreholes KAV01 and KLX02

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December 2003

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Keywords: RAMAC, Radar, Directional antenna.

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 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 Figure 5-1. New values for strike and dip are therefore updated in Tables 5-2 and 5-3.

Contents

1 Introduction

This document reports the data gained in directional radar measurements (RAMAC) in the core-drilled boreholes KLX02 and KAV01, Oskarshamn. This report includes measurements from 70 to approximately 730 m depth in borehole KAV01 and measurements from 200 to approximately 1000 m in borehole KLX02. The two boreholes are drilled with a diameter of 76 mm.

All measurements were conducted by Malå Geoscience AB/RAYCON during October 2003 in accordance with the instructions and guidelines from SKB (Activity plans AP PS 400-03-032 and AP PS 400-03-055 respectively and method description SKB MD 252.020, SKB internal controlling documents) and under supervision of Leif Stenberg, SKB. The location of the boreholes is shown in Figure 1-1.

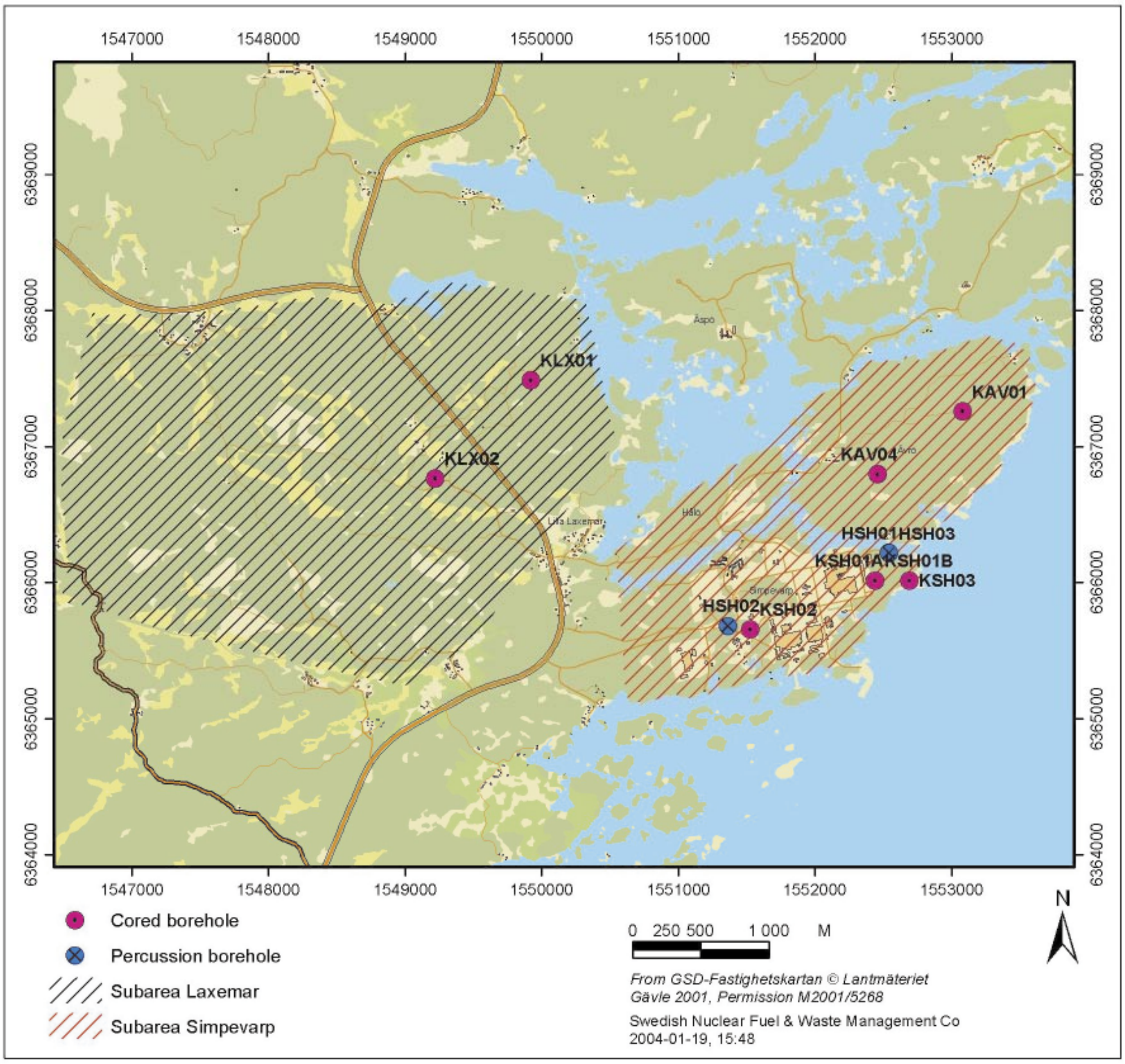


Figure 1-1. *General overview over subareas Simpevarp and Laxemar in site Oskarshamn. The location of KAV01 and KLX02 is shown in the figure.*

2 Objective and scope

The objective of the radar surveys is 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. The resulting 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).

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.

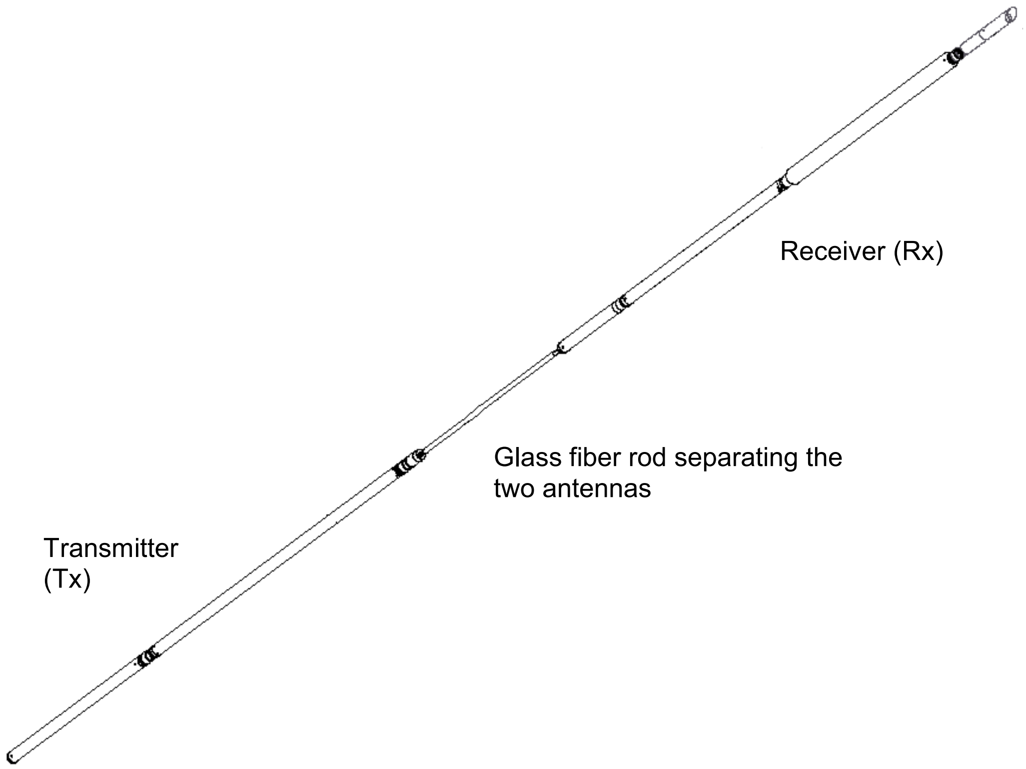


Figure 3-1. *Example of a borehole radar antenna.*

4 Execution

4.1 Execution of measurements

4.1.1 RAMAC radar

The measurements in KAV01 and KLX02 were carried out with directional radar antennas. The directional antenna has central frequency of 60 MHz.

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

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

For more information on system settings used in the investigation of KAV01 and KLX02 see Table 4-1 and 4-2 below.

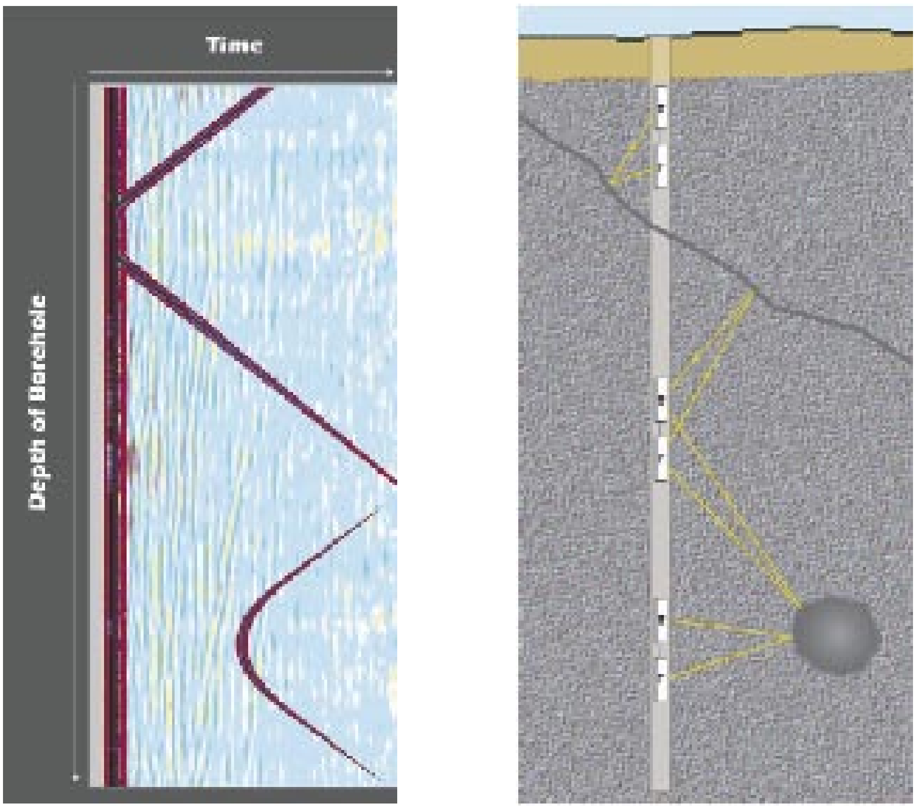


Figure 4-1. *The principle of radar borehole reflection survey and an example of result.*

Table 4-1. Radar logging information from Oskarshamn KAV01.

Site: Oskarshamn	**Logging company:**	**RAYCON**
BH: KAV01	**Equipment:**	**SKB RAMAC**
Type: Directional	**Manufacturer:**	**MALÅ GeoScience**
Operators: CG	**Antenna**	
	Directional (60 MHz)	
Logging date:	2003-10-07	
Reference:	T.O.C.	
Sampling frequency (MHz):	656	
Number of samples:	512	
Number of stacks:	32	
Signal position:	365.72	
Logging from (m):	75.4	
Logging to (m):	737.4	
Trace interval (m):	0.5	
Antenna separation (m):	5.73	

Table 4-2. Radar logging information from Oskarshamn KLX02.

Site: Oskarshamn	**Logging company:**	**RAYCON**
BH: KLX02	**Equipment:**	**SKB RAMAC**
Type: Directional	**Manufacturer:**	**MALÅ GeoScience**
Operators: CG	**Antenna**	
	Directional (60 MHz)	
Logging date:	2003-10-09	
Reference:	T.O.C	
Sampling frequency (MHz):	656	
Number of samples:	512	
Number of stacks:	32	
Signal position:	365.72	
Logging from (m):	206.4	
Logging to (m):	1003.4	
Trace interval (m):	0.5	
Antenna separation (m):	5.73	

4.1.2 Length measurements

During logging the depth recording for the RAMAC systems is taken care of by a measuring wheel mounted on the cable winch.

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 gray 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 4-2 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/.

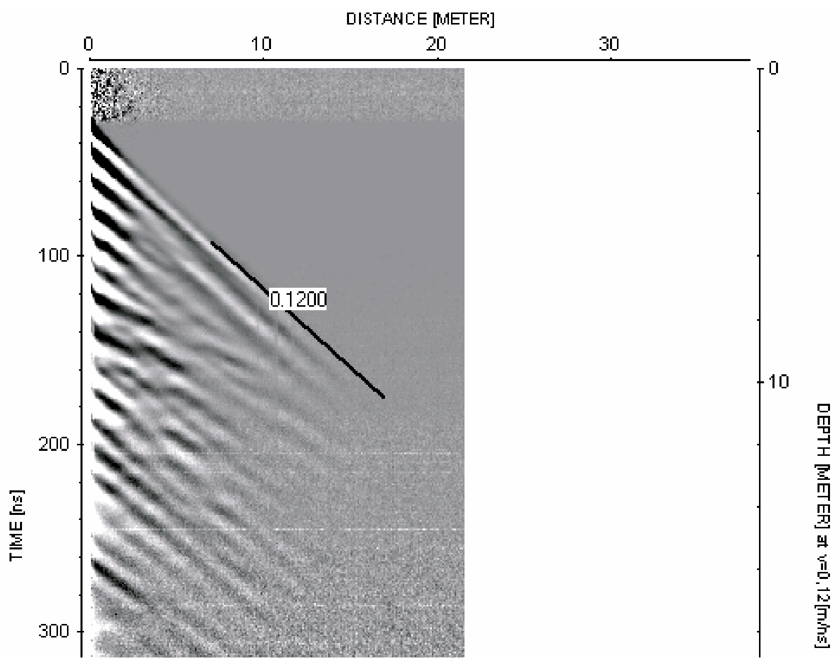


Figure 4-2. *Results from velocity measurements in KSH01B with 100 MHz dipole antennas /1/.*

The visualization of data in Appendix 1 to 2 is made with RadInterSKB, a Windows based processing software for filtering and analysis of borehole radar data. The processing steps are shown in Table 4-4 to 4-5.

RadinterSKB was also used for the interpretation of both the intersection angle between the borehole axis and the planes visible on the radargrams and 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 to 5-3.

Table 4-4. Processing steps for borehole radar data in KAV01.

Site: Oskarshamn	**Logging company:**	**RAYCON**
BH: KAV01	**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 KLX02.

Site: Oskarshamn	**Logging company:**	**RAYCON**
BH: KLX02	**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 Figure 5-1. New values for strike and dip are therefore updated in Tables 5-2 and 5-3.

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 KAV01 and KLX02 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 activities is Field Notes 117 and 147 respectively.

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 and 2. It should be remembered that the images in Appendix 1 and 2 is only a composite picture of all events 360 degrees around the borehole, and do not reflect the orientation of the structures.

Only the larger clearly visible structures are interpreted in RadinterSKB. A number of minor structures also exist, indicated in Appendix 1 and 2 (see for instance around 700 m depth in KAV01 and around 860 m depth in KLX02).

It should also be pointed out that reflections interpreted will in some cases not reach the borehole.

The data quality from KAV01 and KLX02 (as seen in Appendix 1 and 2) 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 KAV01 from a depth of 420 m and in KLX02 from 780 m depth. This conductive environment of course also reduces the possibility to distinguish and interpret the single reflectors.

In Table 5-1 the distribution of identified reflectors along the borehole are listed for KAV01 and KLX02. The results of the interpretation of the radar measurements from KAV01 and KLX02 are presented in Tables 5-2 to 5-3. 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 5-1. As the boreholes are near vertical (>85 degrees) the direction to object is calculated using magnetic roll. This direction and the intersection angle are also recalculated to strike and dip, also given in Tables 5-2 and 5-3. 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.

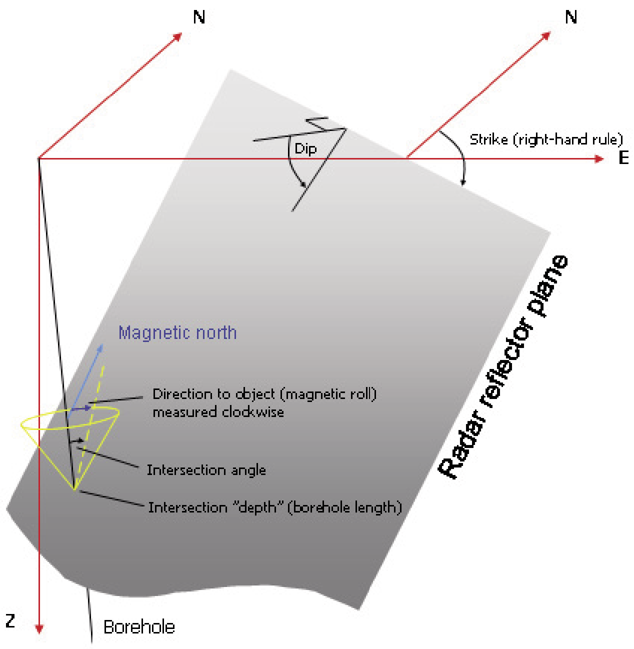


Figure 5-1. *Definition of intersection angle, direction to object using magnetic roll, dip and strike using the right hand rule as presented in Tables 5-2 and 5-3.*

Table 5-1. Distribution of identified reflectors in Oskarshamn KAV01 and KLX02.

Intersection depth	KAV01	KLX02
0–50	1	1
50–100		
100–150	3	
150–200	1	
200–250	4	1
250–300	2	4
300–350	4	1
350–400	2	2
400–450	3	3
450–500	3	3
500–550	1	
550–600	3	1
600–650	5	5
650–700	4	5
700–750	1	4
750–800		3
800–850		2
850–900		3
900–950		3
950–1000		2

Table 5-2. Interpretation of the directional antenna in KAV01.

RADINTER MODEL INFORMATION
(Directional antenna)

Site:	**Oskarshamn**
Borehole name:	**KAV01**
Nominal velocity (m/μs):	**120.0**

Name	Intersection depth	Intersection angle	Direction to object (magnetic roll)	Interpreted Dip/Strike
1	4.0	5	114	85 / 204
2	128.5	54	345±	36 / 75±
3	136	41	333	49 / 63
4	141.4	24	303	66 / 33
5	187.4	39	297	51 / 27
6	209.4	12	123	78 / 213
7	213.9	45	273±	45 / 3±
8	220.1	45	279	45 / 9
9	248.8	42	306±	48 / 36±
10	250.5	6	216±	84 / 306±
11	282.9	59	291±	31 / 21±
12	305.3	29	318	61 / 48
13	309.2	43	288	47 / 18
14	327.4	10	345	80 / 75
15	348.1	10	267	80 / 357
16	376.4	72	-	-
17	396.5	78	171±	12 /261±
18	438.6	54	204	36 / 295
19	444.5	55	183±	35 / 273±
20	447.3	2	24	88 / 114
21	453.5	53	357	37 / 87
22	479.7	28	153	62 / 243
23	489.4	46	348	44 / 78
24	532.2	70	324±	20 / 54±
25	554.0	66	222	24 / 312
26	591.5	3	354	87 / 84
27	592.1	59	-	-
28	609.9	37	330	53 / 60
29	617.8	47	327	43 / 57
30	628.7	16	-	-
31	630.7	39	186	51 / 276
32	635.9	35	3	55 / 93
33	653.5	30	-	-
34	676.2	85	-	-
35	677.3	68	324±	22 / 54±
36	689.8	46	354	44 / 84
37	722.1	43	258	47 / 348

Table 5-3. Interpretation of the directional antenna in KLX02.

RADINTER MODEL INFORMATION (Directional antenna)				
Site:	**Oskarshamn**			
Borehole name:	**KLX02**			
Nominal velocity (m/μs):	**120.0**			
Name	**Intersection depth**	**Intersection angle**	**Direction to object (magnetic roll)**	**Interpreted Dip/Strike**
1	47.6	5	306±	90 / 82±
2	208.8	17	123	78 / 82
3	261.2	35	312	60 / 82
4	261.7	21	150	74 / 79
5	265.4	37	147	58 / 82
6	267.2	35	333	60 / 82
7	340	53	339	42 / 82
8	367.4	63	9	33 / 87
9	386.5	58	63	38 / 79
10	417.7	54	174	42 / 79
11	440.3	46	15	50 / 83
12	446.7	45	330	50 / 82
13	456.3	70	324	25 / 83
14	463.4	27	165	69 / 83
15	467.1	6	228±	90 / 79±
16	569.4	7	42	89 / 78
17	609.0	72	231	24 / 83
18	609.7	10	195	86 / 83
19	617.4	21	90	75 / 83
20	641.1	39	21	58 / 83
21	653.4	44	9	53 / 83
22	660.6	28	6	69 / 70
23	663.1	67	354	30 / 43
24	674.9	62	-	-
25	688.2	56	207±	41 / 83±
26	713.6	43	-	-
27	720.9	12	30	85 / 47
28	731.9	52	3	45/ 55
29	752	59	-	-
30	776.2	51	9	46 / 48
31	780.4	47	78	50 / 47
32	801.8	63	162	34 / 48
33	816.6	36	6	61 / 52
34	855.8	41	354	56 / 62
35	869.2	59	-	-
36	882.8	62	231	35 / 66
37	909.8	68	204	29 / 66
38	922.2	44	3	53 / 86
39	948.8	47	165	50 / 82
40	976.2	45	153	52 / 82
41	998.1	65	186±	32 / 82±
42	298.7	15	318	80 / 81

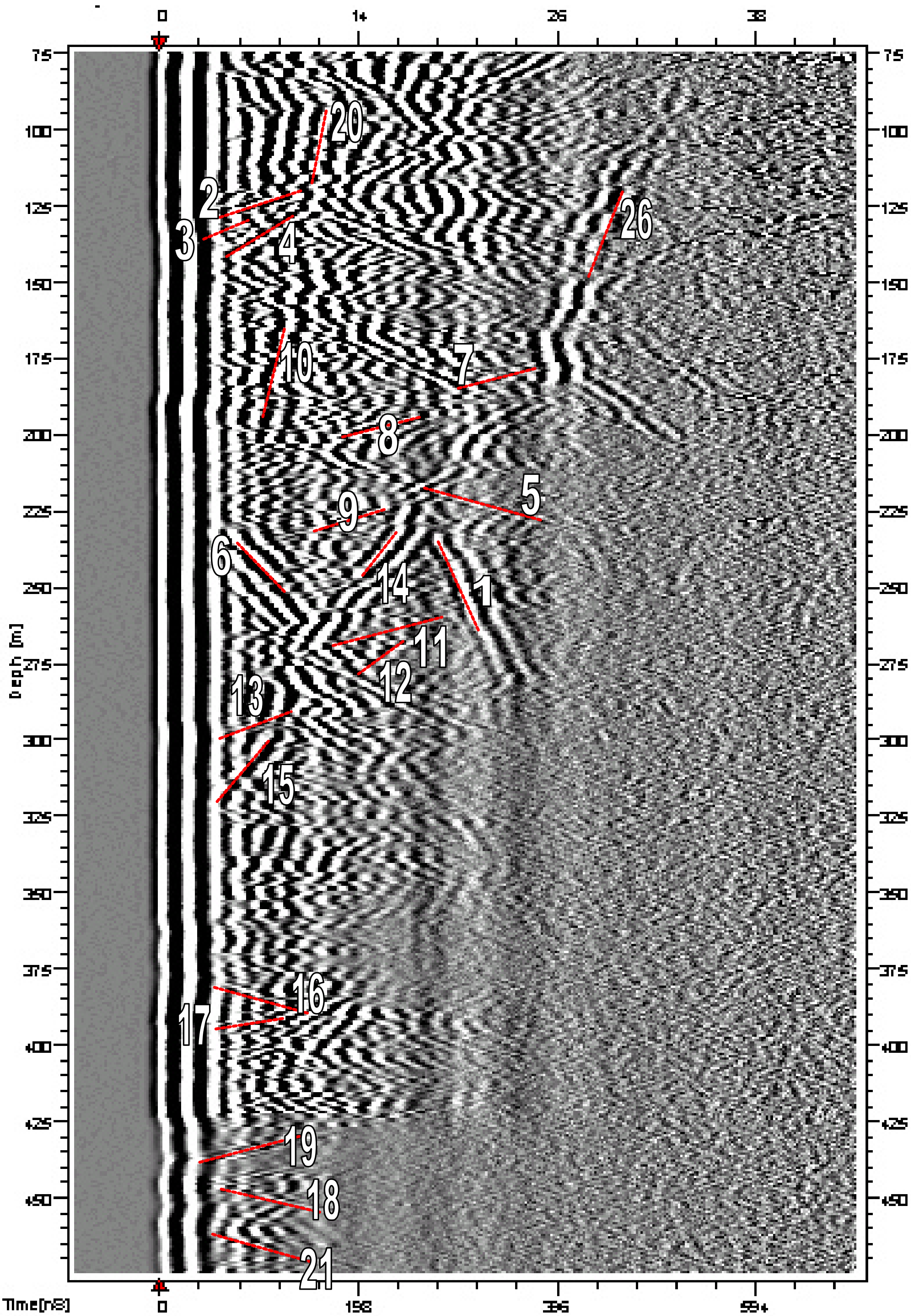
References

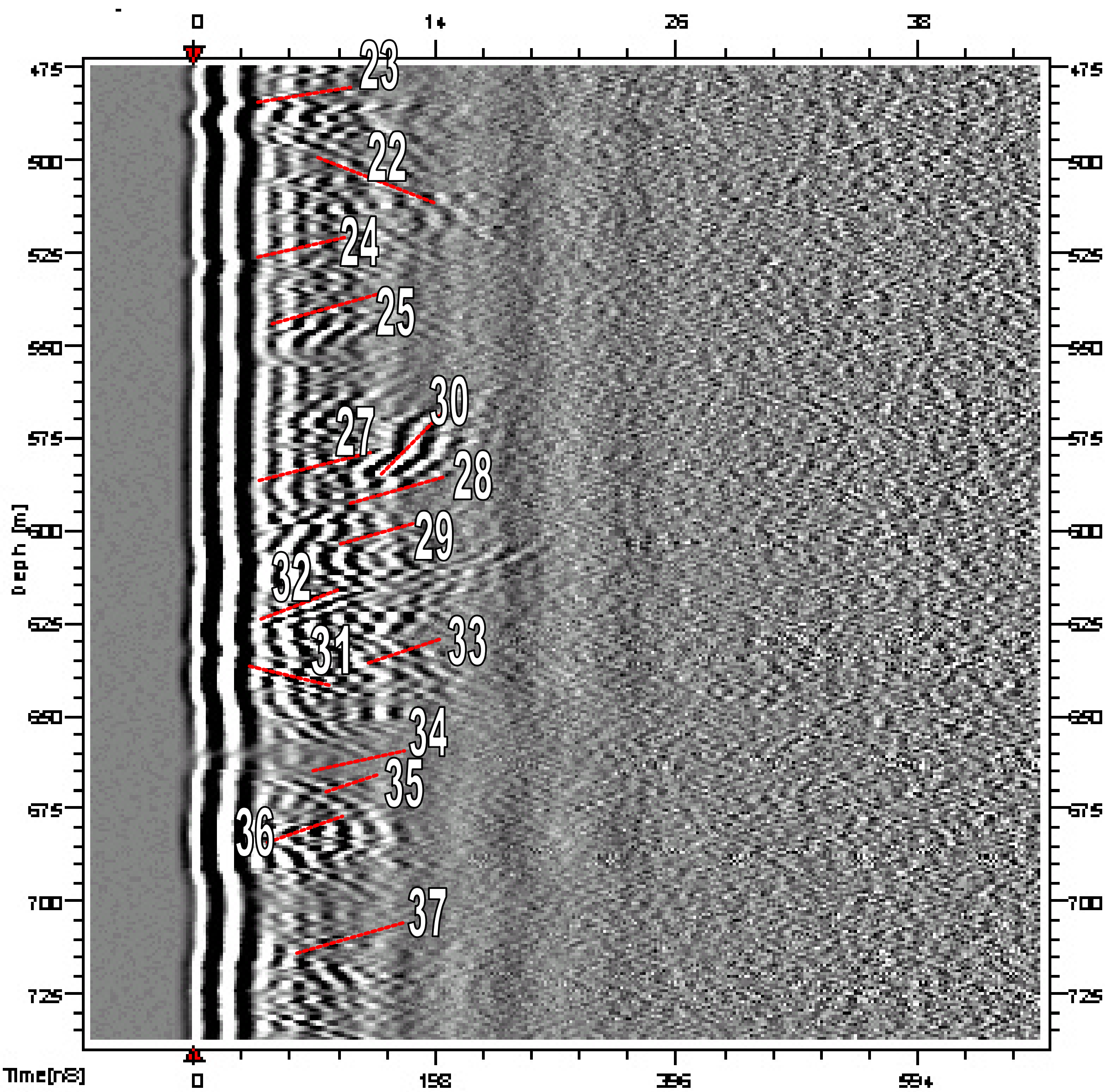
/1/ **Aaltonen J, Gustafsson C, Nilsson P, 2003.** Oskarshamn site investigation. RAMAC and BIPS logging and deviation measurements in boreholes KSH01A, KSH01B and the upper part of KSH02. SKB P-03-73.

Appendix 1

Radar logging with directional antenna 60 MHz, dipole component, in KAV01

Oskarshamn KAV01 with interpretation





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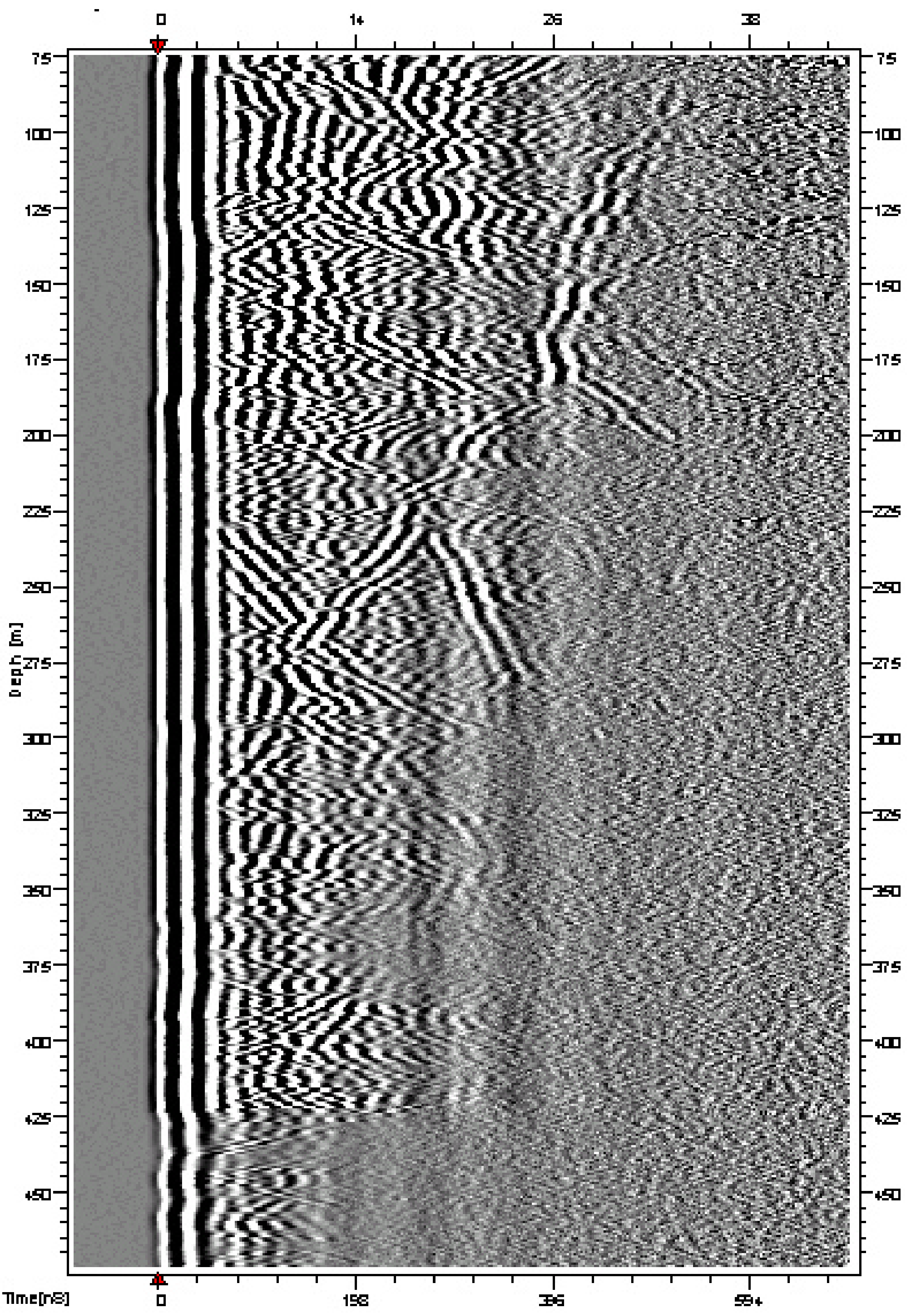
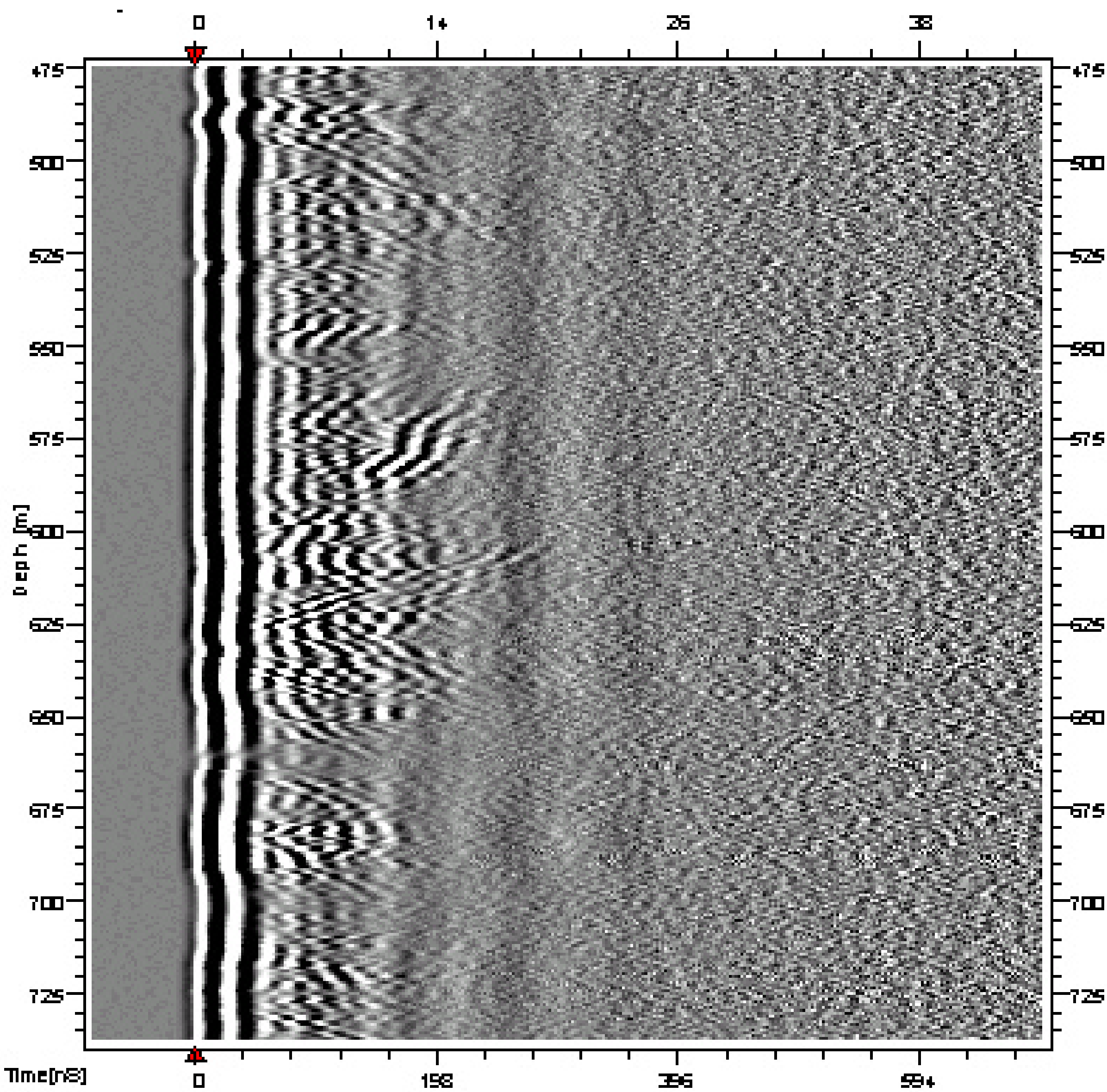
Oskarshamn KAV01

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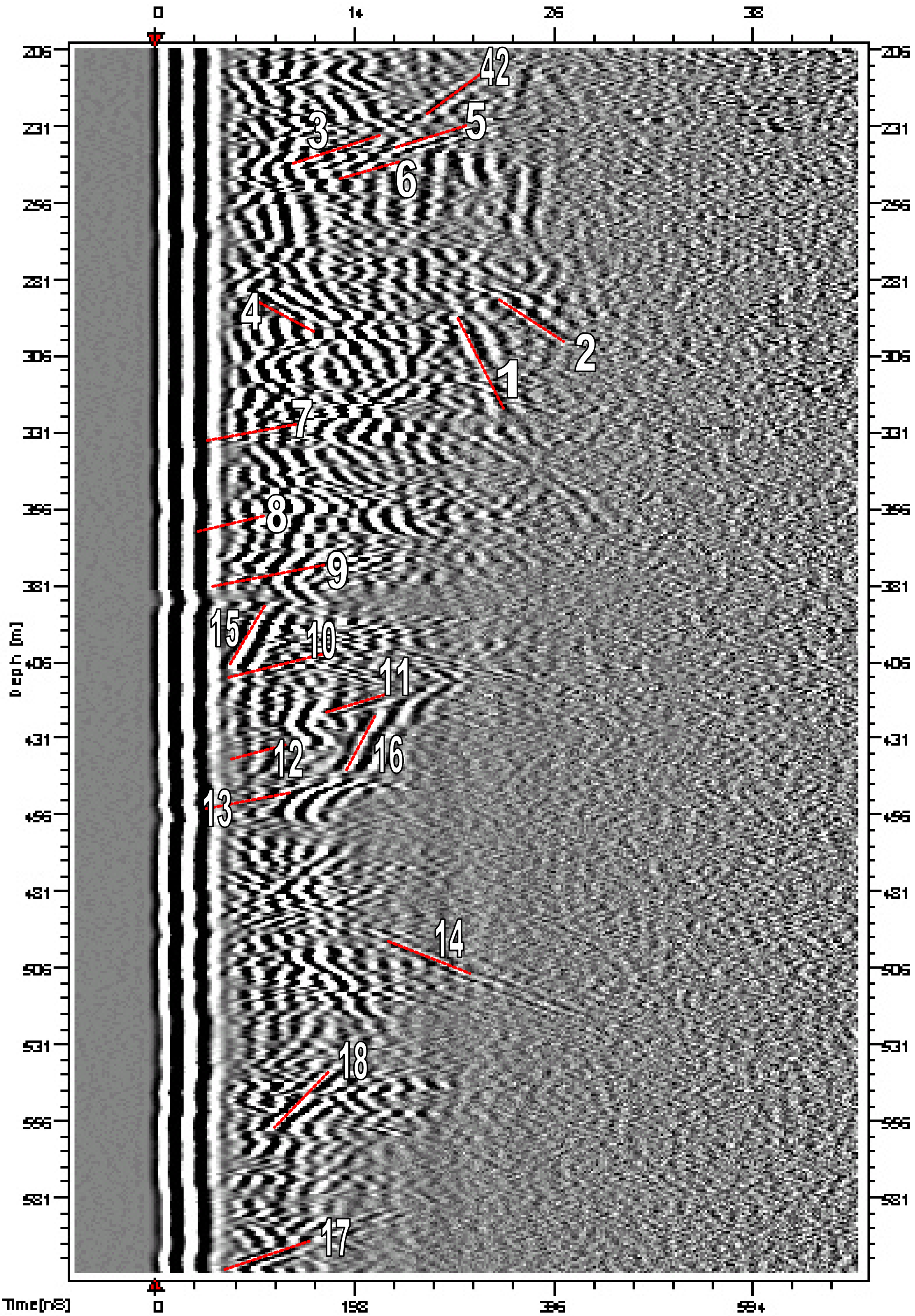
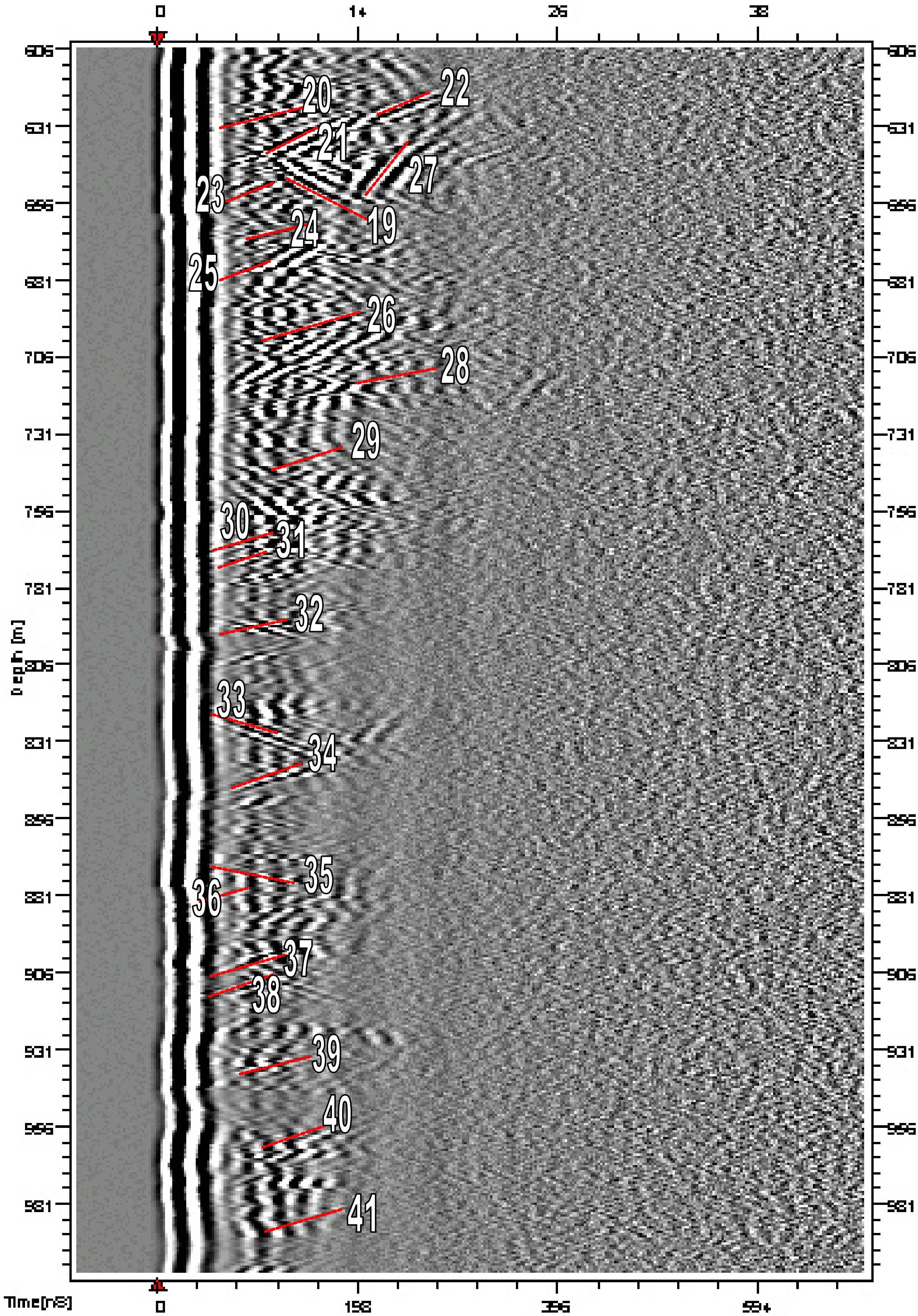
Appendix 2

Radar logging with directional antenna 60 MHz, dipole component, in KLX02

Oskarshamn KLX02 with interpretation





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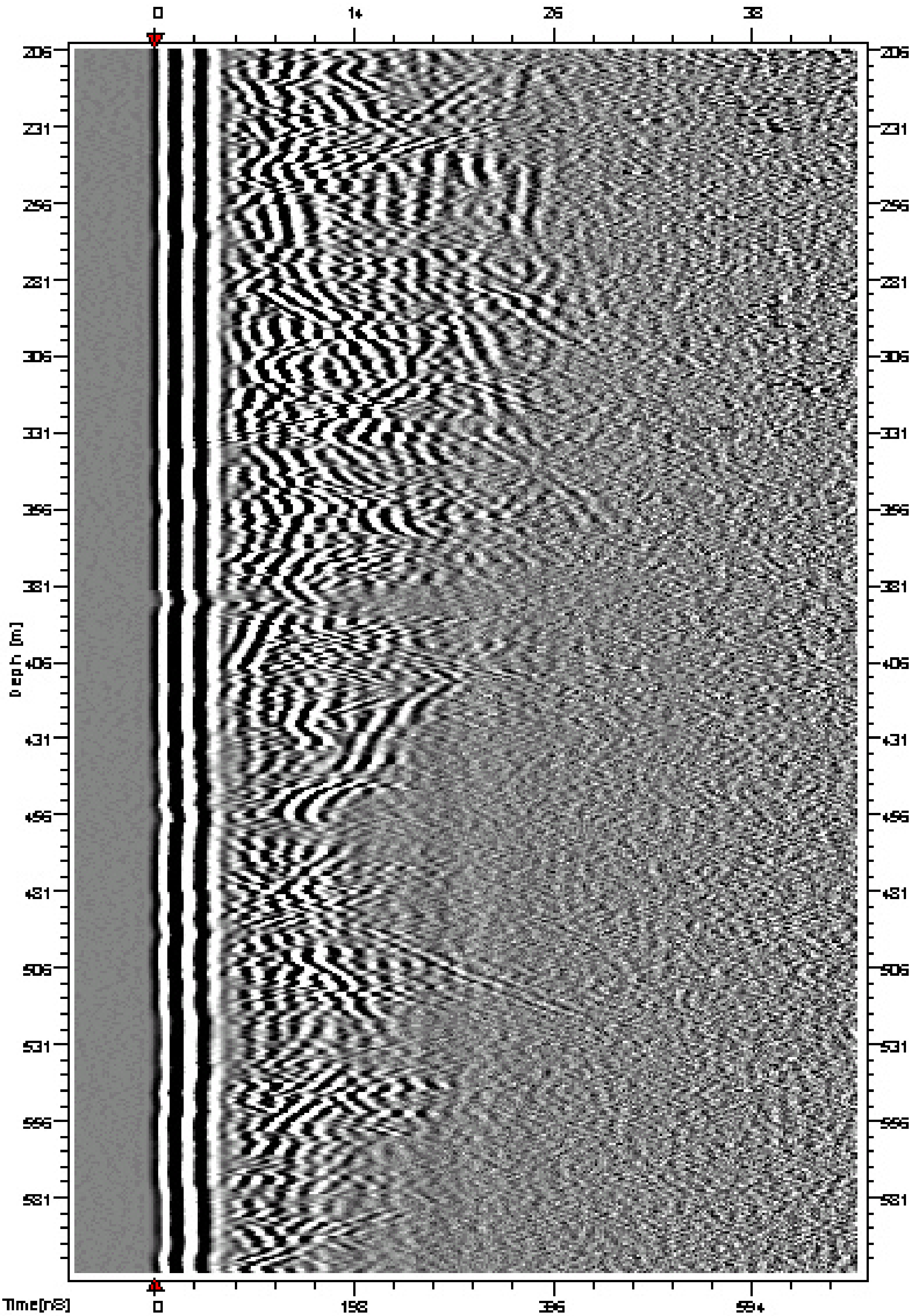
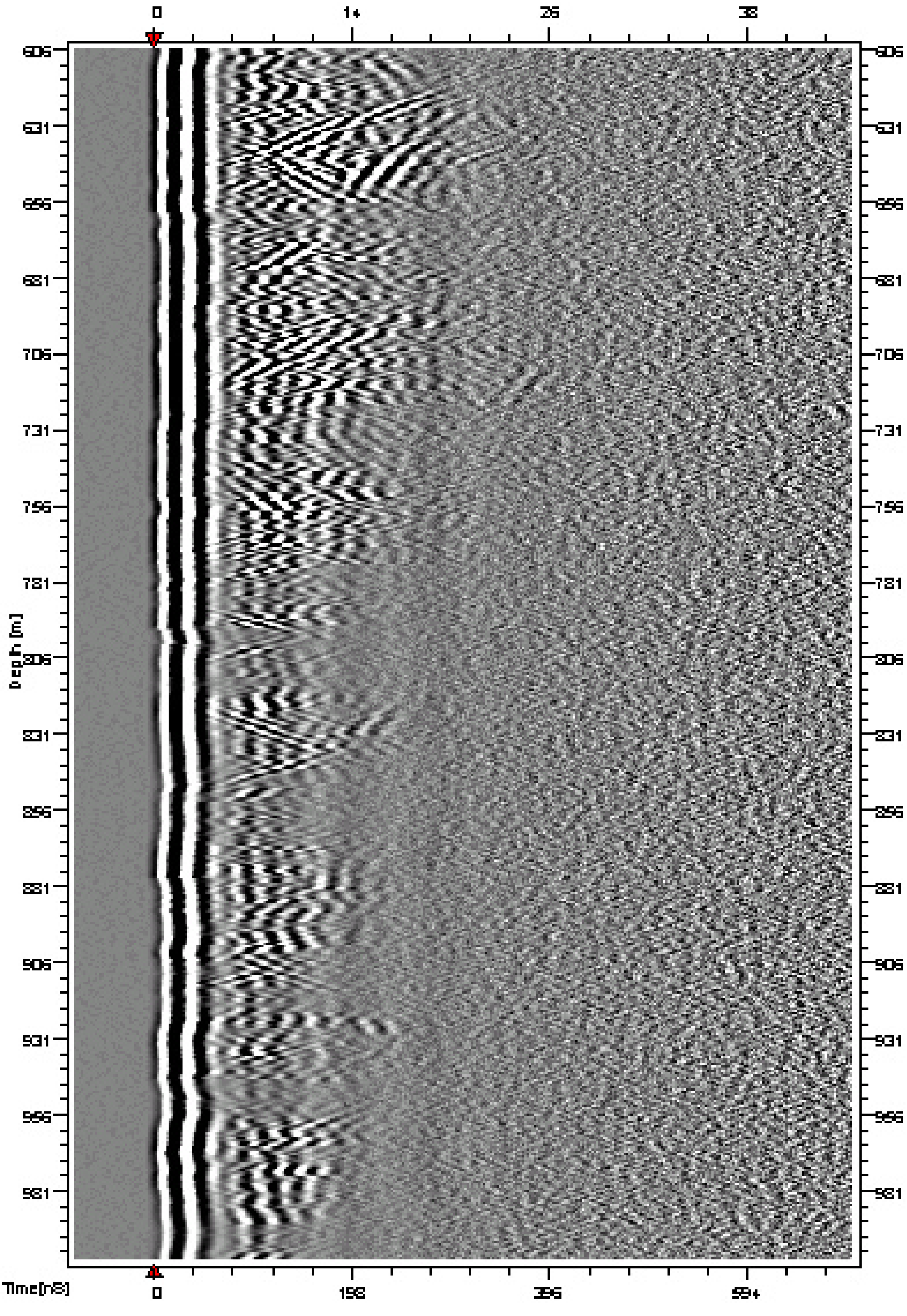
Oskarshamn KLX02

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