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Oskarshamn site investigation

RAMAC and BIPS logging in borehole KLX11A

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June 2006

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Keywords: BIPS, RAMAC, Radar, TV.

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) and BIPS logging in the core drilled borehole KLX11A. All measurements were conducted by Malå Geoscience AB/RAYCON during April 2006.

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 KLX11A was relatively good, 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 210 identified radar reflectors in KLX11A and of these 38 were orientated (strike/dip).

The BIPS images is relatively good along the borehole. Mud covering the lowermost part of the borehole limits the visibility in the bottom part of the borehole. The common discoloring effect from the drilling is very low and makes the core logging easy compared to other boreholes at the Laxemar site.

Sammanfattning

Denna rapport omfattar geofysiska loggningar inom platsundersökningsprogrammet för Oskarshamn. Mätningarna som presenteras här omfattar borrhålsradarmätningar (RAMAC), och BIPS-loggningar i kärnborrhålet KLX11A. Alla mätningar är utförda av Malå Geoscience AB/RAYCON under april 2006.

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 KLX11A var relativt bra, men bitvis med sämre djuppenetration troligen till stor del beroende på en konduktiv miljö. En konduktiv miljö minskar möjligheterna att identifiera strukturer från borrhålsradardata. Dock har 210 radarreflektorer identifierats i KLX11A och av dessa har 38 orienterats (med strykning/stupning).

BIPS bilderna uppvisar en god kvalité längs borrhålet tack vare att borrhålet är relativt förskonad från missfärgning av borrhålsväggen inducerat från borrningen. Lera som täcker den nedre delen av borrhålsväggen i botten på borrhålet försämrar givetvis kvalitén men förutsättningarna för kärnkartering är ändå goda.

Contents

1 Introduction

This report presents 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) and BIPS in the core drilled borehole KLX11A.

The work was carried out in accordance with activity plan AP PS 400-06-032. In Table 1-1 the controlling documents for performing this activity are listed. Both activity plans and method descriptions are SKB's internal controlling documents.

This report includes measurements from 0 to 990 m in KLX11A. The borehole is percussion drilled with a diameter of 195 mm down to 100.06 m, and from there the borehole is core drilled with a diameter of 76 mm.

All measurements were conducted by Malå Geoscience AB/RAYCON during April 2006. The investigation site and location of the boreholes is shown in Figure 1-1.

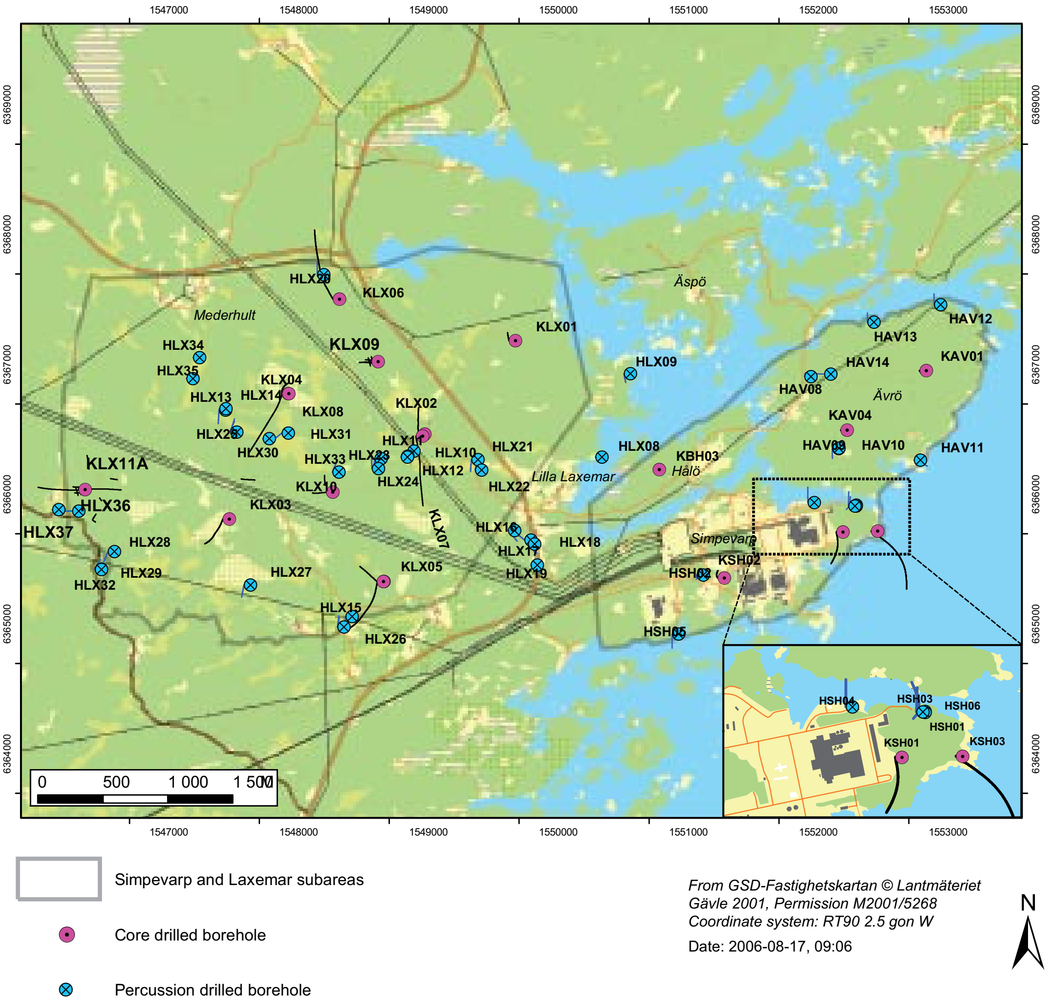
The used investigation techniques comprised:

- Borehole radar measurements (Malå Geoscience AB:s RAMAC system) with 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.

The delivered raw and processed data have been inserted in the database of SKB (SICADA) and data are traceable by the activity plan number.

Table 1-1. Controlling documents for the performance of the activity (SKB´s internal controlling documents).

Activity plan	**Number**	**Version**
Borrhålsradar och BIPS i KLX11A	AP PS 400-06-032	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	2.0



From GSD-Fastighetskartan © Lantmäteriet
Gävle 2001, Permission M2001/5268
Coordinate system: RT90 2.5 gon W
Date: 2006-08-17, 09:06

Figure 1-1. *Map of the location of the borehole KLX11A,on the west side of the Laxemar subarea, Oskarshamn.*

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 rock types as well as fracture distribution and orientation.

This report describes the equipment used for the radar and BIPS 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.

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.

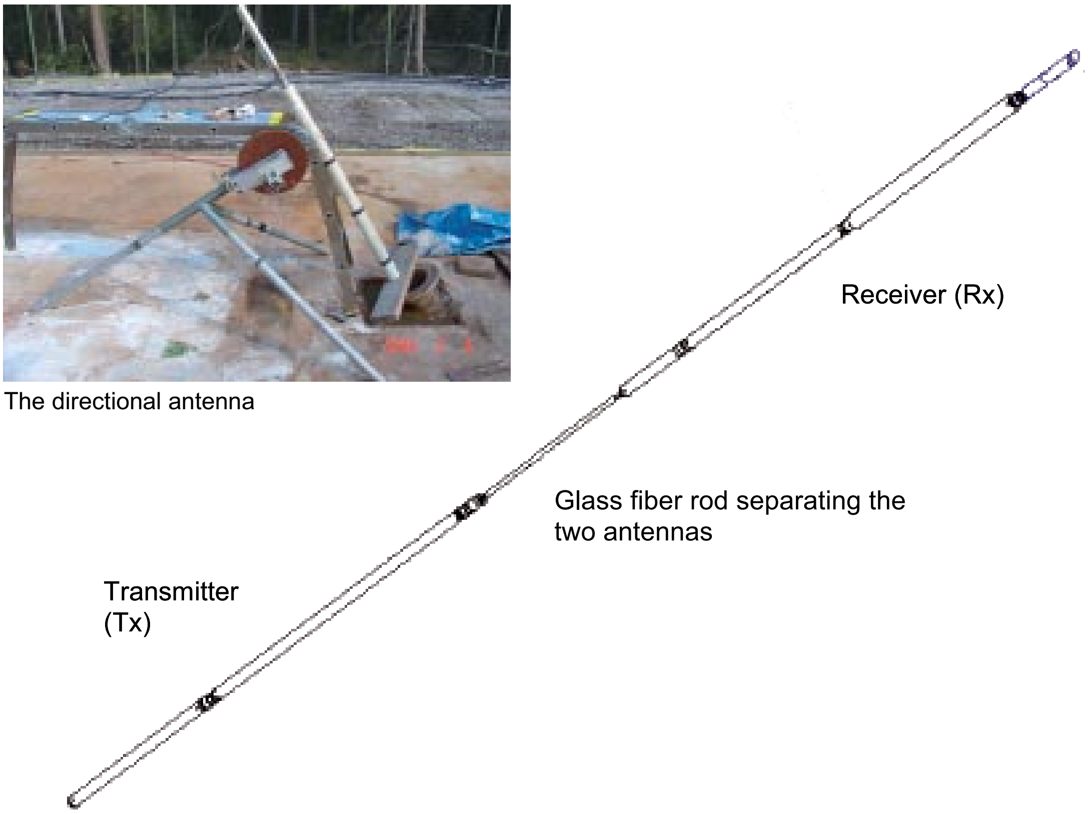

The directional antenna

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, pixel circles are 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).

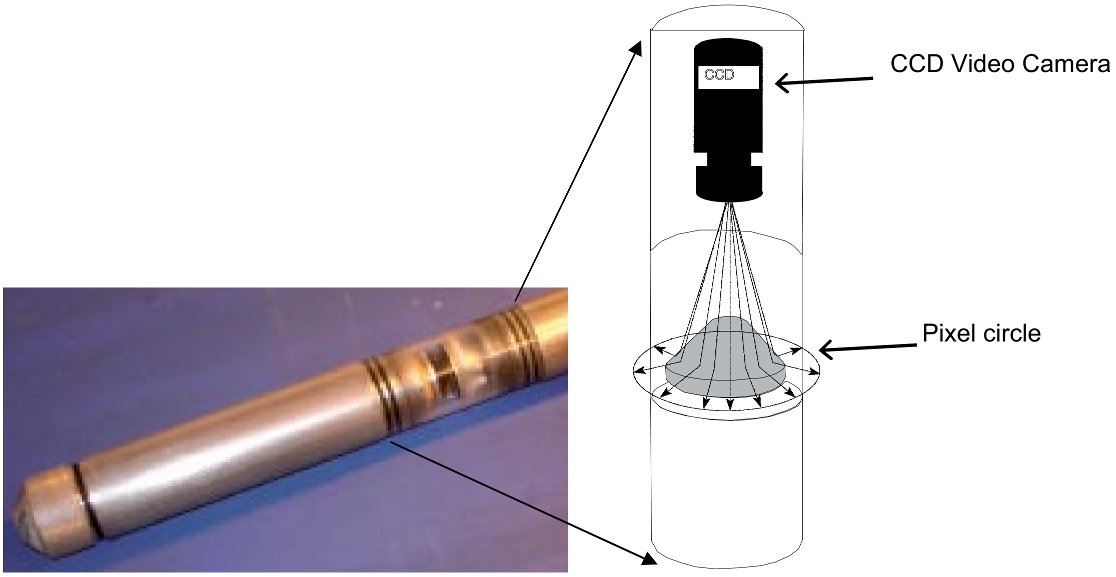


Figure 3-2. *The BIP-system. Illustration of the conical mirror scanning.*

4 Execution

4.1 General

4.1.1 RAMAC Radar

The measurements in KLX11A were carried out with dipole radar antennas, with frequencies of 250, 100 and 20 MHz and with a directional antenna, with a central frequency of 60 MHz.

During logging the dipole antennas (transmitter and receiver) were lowered continuously into the borehole and data were recorded on a field PC along the measured interval. The measurement with the directional antenna is made stepwise, with a short pause for each measurement occasion. The antennas (transmitter and receiver, both for dipole and directional) are kept at a fixed separation by glass fiber rods according to Table 4-1. See also Figures 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 KLX11A. This was performed by measurements in the air, where the receiver antenna and the transmitter antenna are placed apart. While transmitting and measuring the receiver antenna is turned around and by that giving the direction from the receiver antenna to the transmitter antenna. The difference in direction is measured by compass and the result difference achieved from the directional antenna was about 1 degree. This can be considered to be very good due to the disturbed environment, with metallic objects etc at the test site.

For more information on system settings used in the investigation of KLX11A, see Table 4-1 below.

Table 4-1. Radar logging information from KLX11A.

Site:	**Oskarshamn**	**Logging company:**		**MALÅ GeoScience/RAYCON**	
BH:	**KLX11A**	**Equipment:**		**SKB RAMAC**	
Type:	**Directional/Dipole**	**Manufacturer:**		**MALÅ GeoScience**	
Operator:	**CG**	**Antenna**			
		Directional	**250 MHz**	**100 MHz**	**20 MHz**
Logging date:		06-04-06--07	06-04-06	06-04-06	06-04-06
Reference:		T.O.C.	T.O.C.	T.O.C.	T.O.C.
Sampling frequency (MHz):		615	2,424	891	239
Number of samples:		512	619	518	518
Number of stacks:		32	Auto	Auto	Auto
Signal position:		410.5	–0.35	–0.35	–1.42
Logging from (m):		105.4	1.5	2.6	6.25
Logging to (m):		953.4	988.9	987.5	987.9
Trace interval (m):		0.5	0.1	0.2	0.25
Antenna separation (m):		5.73	2.4	3.9	10.05

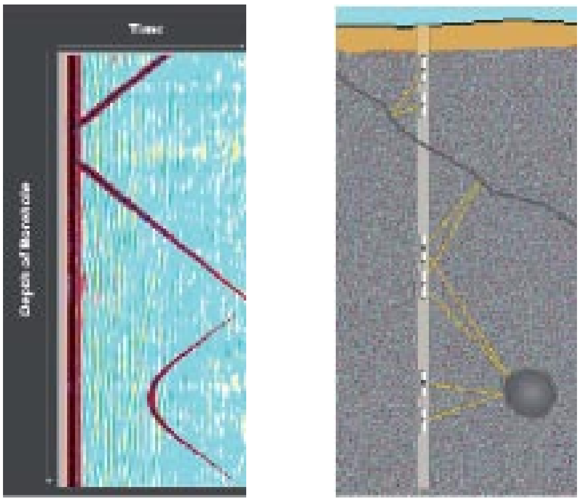


Figure 4-1. *The principle of radar borehole reflection survey and an example of result.*

4.1.2 BIPS

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

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

A gravity sensor was used to measure the orientation of the images in the borehole KLX11A.

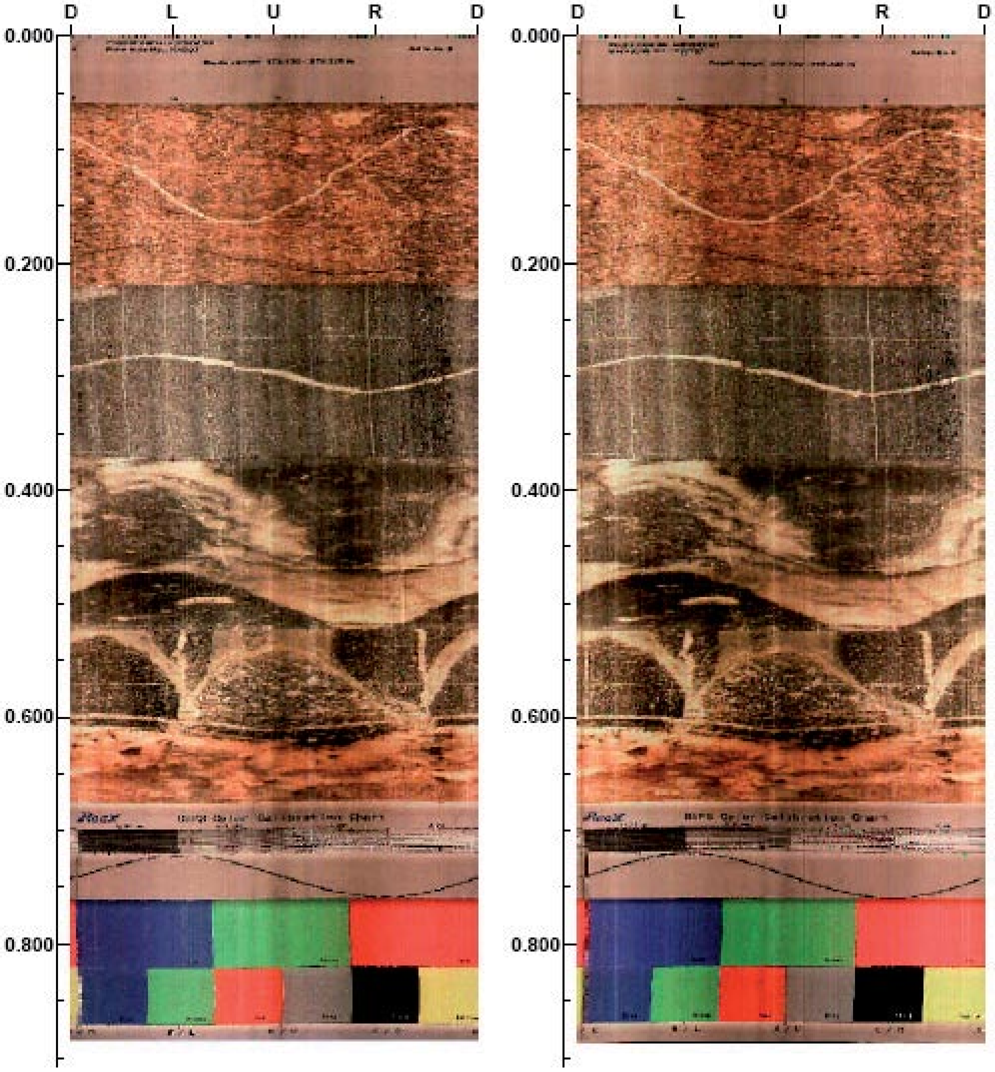
In order to control the quality of the system, calibration measurements were performed in a test pipe before logging and after logging. Figure 4-2 show the results of the test logging performed before and after the logging of KLX11A. The results showed no difference regarding the colours and focus of 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. The logging is measured from TOC (Top of Casing). The length is adjusted to the bottom of casing when visible in the BIPS image.

During the BIPS logging in core drilled boreholes, where the reference marks in the borehole wall is visible on the image, the position where the 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. The non-adjusted length 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 KLX11A **After KLX11A**

Figure 4-2. *Results from logging in the test pipe before and after the logging campaign in April, 2006.*

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 100 cm in the deepest parts of a 1,000 m deep borehole.

The depth divergence is taken into account 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 radar wave propagation and reflection 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 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. For this logging campaign the velocity determination was performed between KLX07A and KLX07B by keeping the transmitter fixed in one borehole while moving the receiver downwards in a nearby borehole. The velocity measurement was performed with the 20 MHz antennas in boreholes KLX07A and KLX07B /1/.

The result is plotted in Figure 4-3 and the calculation shows a velocity varying between 110 and 117 m/micro seconds. The lower velocities most probably represent a fracture zone in the depth interval 40 to 60 m.

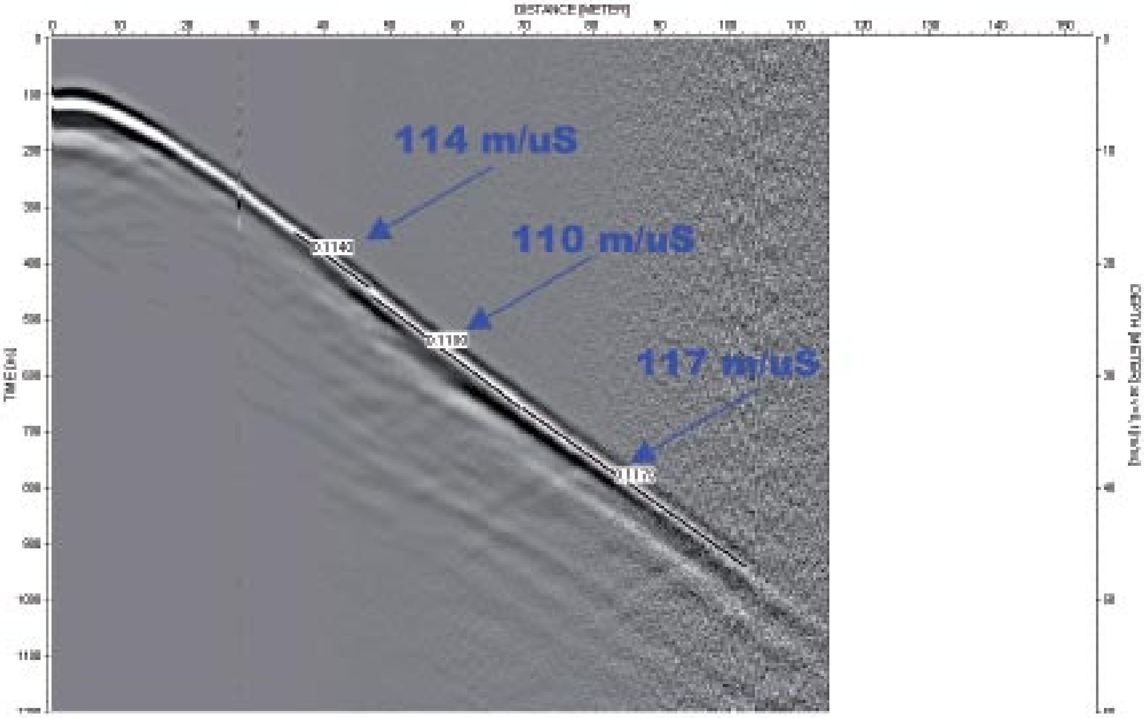


Figure 4-3. Results from velocity measurements /1/.

The visualization of data 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 in Table 4-2 below refer to Appendix 1 in this report. The filters applied affect the whole borehole length and are not always suitable in all parts, depending on the geological conditions and conductivity of the borehole fluid. During interpretation further processing can be done, most often in form of bandpass filtering. This filtering can be applied just in parts of the borehole, where needed.

For the interpretation of the intersection angle between the borehole axis and the planes visible on the radargrams the RadinterSKB software has been used. The interpreted intersection points and intersection angles of the detected structures are presented in the Table 5-2 and are also visible on the radargrams in Appendix 1.

Table 4-2. Processing steps for borehole radar data from KLX11A.

Site:	**Oskarshamn**	**Logging company:**		**MALÅ GeoScience/RAYCON**	
BH:	**KLX11A**	**Equipment:**		**SKB RAMAC**	
Type:	**Directional/Dipole**	**Manufacturer:**		**MALÅ GeoScience**	
Interpret:	**JG**	**Antenna**			
		Directional	**250 MHz**	**100 MHz**	**20 MHz**
Processing:		Move start time (–32 samples)	Move start time (–19.8)	Move start time (–22.5)	Move start time (–82)
		DC shift (370–510)	DC shift (190–240)	DC shift (460–520)	DC shift (1,800–2,100)
		Time gain (start 59 lin 100 exp 1)	Gain (start 15 lin 1.7 exp 1)	Gain (start 28 lin 2.5 exp 0.6)	Gain (start 129 lin 2.5 exp 0.2)
		(FIR)			

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 visible in the BIPS image. For printing of the BIPS images the printing software BIPP from RaaX was used.

4.3 Nonconformities

No nonconformities occurred during the logging campaign in April, 2006.

5 Results

The results from the BIPS measurements for KLX11A were delivered as raw data (*.bip-files) on CD-ROM disks and MO-disks to SKB 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 digital data and VHS tapes stored by SKB.

The RAMAC radar data was delivered as raw data (file format *.rd3 (dipole antennas) or *.rd5 (directional antenna)) for KLX11A 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 delivered raw and processed data have been inserted in the database of SKB (SICADA) and data are traceable by the activity plan number.

5.1 RAMAC logging

The results of the interpretation of the radar measurements are presented in Tables 5-1 to 5-4. Radar data is also visualized in Appendix 1. It should be remembered that the images in Appendix 1 are 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. An overview of the borehole is given in Figure 5-1 below. A number of minor structures also exist but not interpreted as indicated in Appendix 1. Often a number of structures can be noticed, but most probably lying so close to each other that it is impossible to distinguish one from the other. Larger structures parallel to the borehole, if present, are also indicated in Appendix 1. 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.

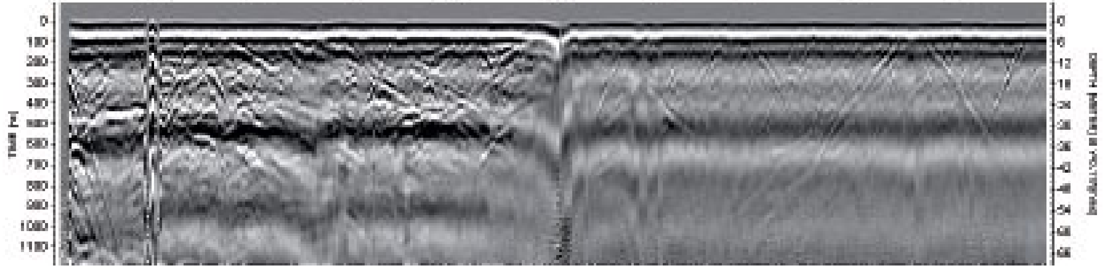


Figure 5-1. An overview (20 MHz data) of the radar data for the borehole KLX11A.

The data quality from KLX11A, (as seen in Appendix 1) is relatively god, but in parts of lower quality due to more electrical conductive conditions. A conductive environment makes the radar wave to attenuate, which decreases the penetration. This conductive environment of course also reduces the possibility to distinguish and interpret possible structures in the rock which otherwise could give a reflection.

This effect is also seen in the directional antenna for KLX11A, which makes it more difficult to interpret the direction to the identified structures.

Further on, depending on the size of the borehole, the conductivity and the antenna frequency, so called ringing can occur, which again makes the interpretation of single structures quite complicated. This is seen for instance in the data from KLX11A, (250 and 100 MHz data) for the first 100 m, where the borehole diameter is larger, see Figure 5-2.

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 degrees.

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 depth compared to a higher frequency. If structures can be identified with all three 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 borehole are listed for KLX11A.

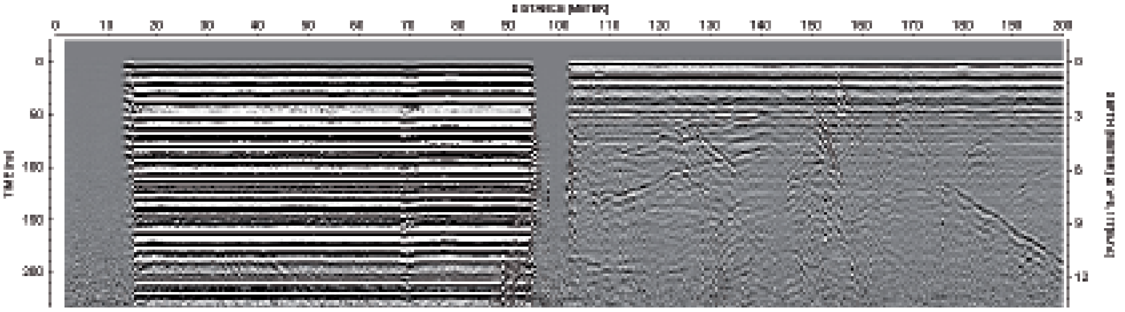


Figure 5-2. Example of data from KLX11A, 250 MHz. The effect of the two different borehole diameters are clearly seen, in the amount of so called ringing, in the upper part compared to the lower part of the borehole. This ringing appears to a higher degree in measurements with higher antenna frequency.

Table 5-1. Identified structures as a function of depth in KLX11A.

Depth (m)	No. of structures
–100	10
100–150	12
150–200	9
200–250	14
250–300	18
300–350	6
350–400	7
400–450	7
450–500	7
500–550	10
550–600	12
600–650	9
650–700	18
700–750	12
750–800	10
800–850	12
850–900	18
900–950	11
950–	9

Table 5-2 summarises the interpretation of radar data from KLX11A. The direction to the reflector (object) is also given. As seen some radar reflectors in Table 5-2 are marked with ±, which indicates an uncertainty in the interpretation of direction. The direction can in these cases be ±180 degrees. The direction to the reflector (object) is defined in Figure 5-3. As the borehole inclination is less than 85 degrees the direction to object is calculated using gravity roll. The direction to object and the intersection angle are recalculated to strike and dip, also given in Table 5-2. 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.

Observe that a structure can have several different angles, if the structure is undulating, and thereby also different intersection depths could be given. For example for structure 115 and 115x in Table 5-2 and Appendix 1. Only the uppermost intersection is presented.

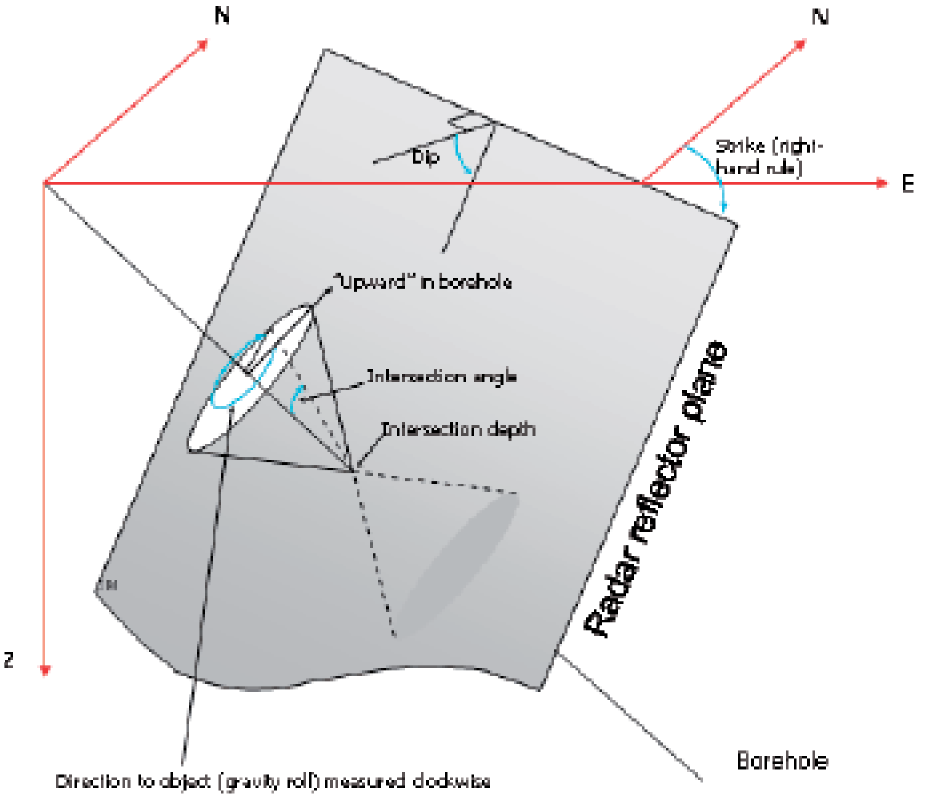


Figure 5-3. Definition of intersection angle, direction to object using gravity roll, dip and strike using the right hand rule as presented in Table 5-2.

Table 5-2. Interpretation of radar reflectors from the dipole antennas 250, 100 and 20 MHz, and the directional antenna 60 MHz in borehole KLX11A.

RADINTER MODEL INFORMATION
(Directional antenna)

Site:	**Oskarshamn**
Borehole name:	**KLX11A**
Nominal velocity (m/μs):	**117.0**

Name	Intersection depth	Inter-section angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
191	–42.3	7					
1	–0.9	16					
4	8.3	38					
5	12.3	56					
2	49.0	24					
6	53.2	60					
7	58.0	56					
3	65.1	29					
8	72.3	79					
22x	98.5	8					
13x	107.7	15					
9	108.5	68					
13	118.2	35					
10	119.8	68					

RADINTER MODEL INFORMATION
(Directional antenna)

Site:	**Oskarshamn**
Borehole name:	**KLX11A**
Nominal velocity (m/µs):	**117.0**

Name	Intersection depth	Inter-section angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
11	123.8	75					
190	125.6	22					
12	125.8	74					
22	133.6	11	144	65	309		
14	136.2	63					
16	139.3	71					
15	142.2	70					
17	144.6	36					
18	153.2	63					
19	162.5	84					
21	169.3	78					
20	171.4	26					
25	176.5	82					
24	178.2	6					
26	179.0	68					
27	180.5	68					
28	195.0	78					
29	204.6	61					
23	205.7	5					
30	210.1	59					
61	211.4	10	336	83	324		
31	211.8	71					
32	219.1	58					
44x	222.2	9					
33	222.9	56					
34	235.2	60					
44	243.9	13	48 ±	89	215	66	41
36	246.7	52					
37	248.2	44					
39	248.9	73					
38	249.3	65					
40	251.8	61					
35	252.0	11					
51	252.8	9					
43	253.2	14					
188	254.3	8	285	86	95		
41	257.7	63					
44xx	259.0	21					
192	266.1	10					
42	266.6	67					
46	267.7	71	33 ±	33	185	10	102
45	278.3	82					

RADINTER MODEL INFORMATION
(Directional antenna)

Site:	**Oskarshamn**
Borehole name:	**KLX11A**
Nominal velocity (m/µs):	**117.0**

Name	Intersection depth	Inter-section angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
47	285.2	31					
48	288.5	57					
49	289.7	63					
52	290.4	50					
50	292.3	60					
53	296.9	59					
54	298.0	33					
55	301.8	53					
56	306.6	71					
57	316.5	73					
58	345.4	37	102	52	256		
60	346.5	48					
59	348.9	50	255	39	86		
62	357.0	17					
62x	360.1	28					
72	363.1	6					
63	364.7	41					
64	366.0	44	282	51	106		
74	388.9	13					
65	398.2	55					
67	418.3	58	276 ±	38	110	35	235
69	431.2	73					
66	436.9	18	114 ±	64	275	79	107
70	439.0	35	90 ±	57	245	57	91
75	442.2	18					
71	443.7	65					
73	448.6	57					
77	461.9	71					
78	467.1	54					
76	467.3	64	84 ±	32	219	29	110
80	473.8	79					
79	476.2	73					
194	479.3	13					
68	484.9	8					
81	510.1	66					
85x	516.9	16	45 ±	88	211	61	39
82	517.0	76					
83	518.2	73					
85	523.4	19					
84	525.8	55					
88	531.1	11	168 ±	61	334	82	336
86	534.9	45					
87	539.8	36					
89	549.7	54					

RADINTER MODEL INFORMATION
(Directional antenna)

Site:	**Oskarshamn**
Borehole name:	**KLX11A**
Nominal velocity (m/µs):	**117.0**

Name	Intersection depth	Inter-section angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
194x	555.2	31					
90	556.6	57					
184	566.6	54					
91	569.5	50					
198	574.0	6	189	65	358		
92	575.5	64	219	16	71		
93	578.9	54	243 ±	31	81	46	213
94	579.4	48					
95	580.9	60					
97	583.2	57					
96	585.7	63					
98	598.6	80	90 ±	22	200	22	137
100	602.0	59					
99	602.7	51	204 ±	22	30	57	186
101	606.3	45					
104	632.9	66					
105	635.0	60	12 ±	49	177	12	19
102	637.3	57	183 ±	12	356	51	171
103	637.6	50					
107	646.3	57					
108	648.1	57					
193	652.3	19					
110	654.7	63					
106	655.4	18					
109	655.7	76					
112	658.7	82					
119	659.2	41	216	35	43		
111	659.9	61					
113	667.8	40					
117	671.0	57	237	26	85		
114	673.2	56					
115	675.5	30	36	75	202		
115x	676.4	27					
116	681.5	7					
195	686.9	25					
118	690.1	65					
199	691.1	64	129	20	253		
120	691.3	38					
121	703.5	37					
122	706.4	64					
124	709.0	83					
123	710.5	43					

RADINTER MODEL INFORMATION
(Directional antenna)

Site:	**Oskarshamn**
Borehole name:	**KLX11A**
Nominal velocity (m/µs):	**117.0**

Name	Intersection depth	Inter-section angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
125	712.8	48					
126	718.4	58					
127	720.2	64					
128	726.8	37					
129	741.6	47					
130	745.8	44					
131	749.2	38					
133	749.8	52	132	29	276		
132	751.1	43					
134	764.3	46	219	30	51		
135	774.1	54					
136	779.7	72					
138	786.5	72					
137	787.9	40					
186	792.4	54					
196	792.9	60					
139	793.2	51	216 ±	22	65	55	204
141	798.0	50					
185	802.7	38					
140	810.0	56	114	32	259		
143	813.4	55	105	35	252		
142	821.9	71					
144	833.1	45					
147	835.7	55					
145	839.2	31					
146	841.0	32					
148	842.3	67	66 ±	34	211	22	125
154	846.7	50					
151xx	847.0	31					
149	847.4	73					
150	851.1	49					
152	853.5	47					
156	853.5	33					
151xxx	853.9	27					
153	854.7	62	33 ±	47	199	15	80
151	855.0	28	279	67	108		
155	857.2	24					
157	860.8	56					
151x	863.7	20					
158	864.3	75					
159	869.0	80					
160	871.6	64	282 ±	40	129	32	245

RADINTER MODEL INFORMATION
(Directional antenna)

Site: **Oskarshamn**
Borehole name: **KLX11A**
Nominal velocity (m/µs): **117.0**

Name	Intersection depth	Inter-section angle	RadInter direction to object (gravity roll)	Dip 1	Strike 1	Dip 2	Strike 2
161	880.0	59					
187	880.5	35					
162	886.5	26					
163	891.6	53					
164	892.2	30					
165	896.7	41					
167	904.3	61					
166	907.3	29	222	45	54		
168	907.3	55	24 ±	63	197	24	41
169	910.6	66					
170	915.0	61					
197	919.4	22					
175	923.1	58					
172	929.2	41					
171	930.8	44	171 ±	25	344	66	172
173	934.5	34					
174	948.1	62					
176	955.7	58					
182	961.9	54					
177	963.9	42					
178	970.1	56					
183	972.1	51					
179	975.1	42	210 ±	29	47	65	202
180	981.4	61					
181	1,020.2	24					
189	1,745.8	1					

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.

Table 5-3. Borehole length intervals in KLX11A with decreased amplitude for the 250 MHz antenna.

Length (m)	Length (m)
145	645
170	655
185	670–680
245–275	690
305	765
345–350	805
465	835
475	855–860
485–515	865–880
525	905–915
575–585	925
596–600	975
635	

Finally, the structures considered as the most important (clear in the radargram, identified with several antenna frequencies, stretching out far from the borehole wall etc) are listed in Table 5-4 below.

Table 5-4. Some important structures in KLX11A.

Borehole	KLX11A
Structures	1, 3, 21, 22, 22x, 23, 35, 43, 4, 44x, 58, 59, 61, 66, 76, 85, 85x, 93, 98, 103, 115, 115x, 133, 143, 151, 151x, 151xx, 151xxx, 153, 154, 179, 188, 189, 190, 191, 192, 194, 197, 195, 195x and 198

Observe that it can be very difficult to classify different structures in an objective manner, along a borehole. This is due to the fact that the water quality (the conductivity) amongst others varies along the borehole length and by that reason affects the results of the radar logging, by for instance attenuating the radar waves differently. Also the intersection angle of the identified structures affects the amplitude on the resulting radargram. A small angle will most often give a increased amplitude than a larger angle, and by that a more clear structure.

5.2 BIPS logging

The BIPS pictures from KLX11A are presented in Appendix 2.

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

To get the best possible depth accuracy, the BIPS images are adjusted to the reference mark on the cable for the logging in KLX11A.

The error in the depth recording depends mainly on 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.

The BIPS images is very dark in section 12 to 96 m. This is due to the large borehole diameter in combination with a dark color of the borehole wall. The light in the camera is not enough to get good images in this section.

From the end of the cone in the borehole to the bottom of the borehole water quality is good but mud covering the lowermost part of the borehole limits the visibility. This effect increases along the borehole. The common discoloring effect induced from the drilling is surprisingly low along the borehole. The Figure 5-4 shows the effect of the automatic iris function in the camera when the camera enters in to a part of the borehole that have either dark or pale colors. When this happens the iris function automatically try to compensate for the strength of the light. This results in a distinct changes on the images.

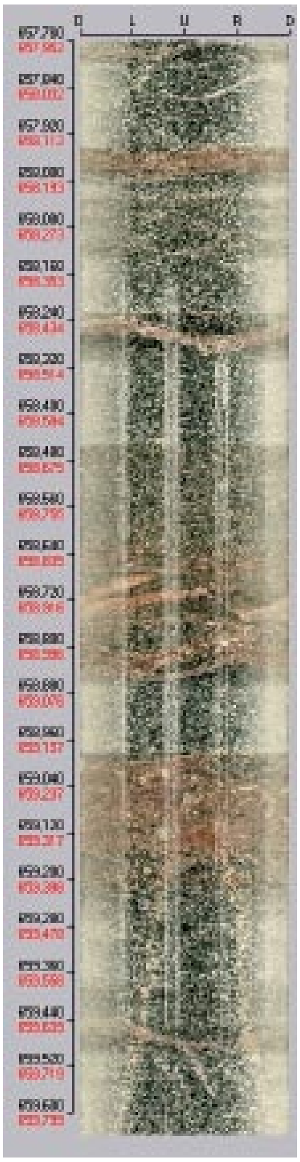


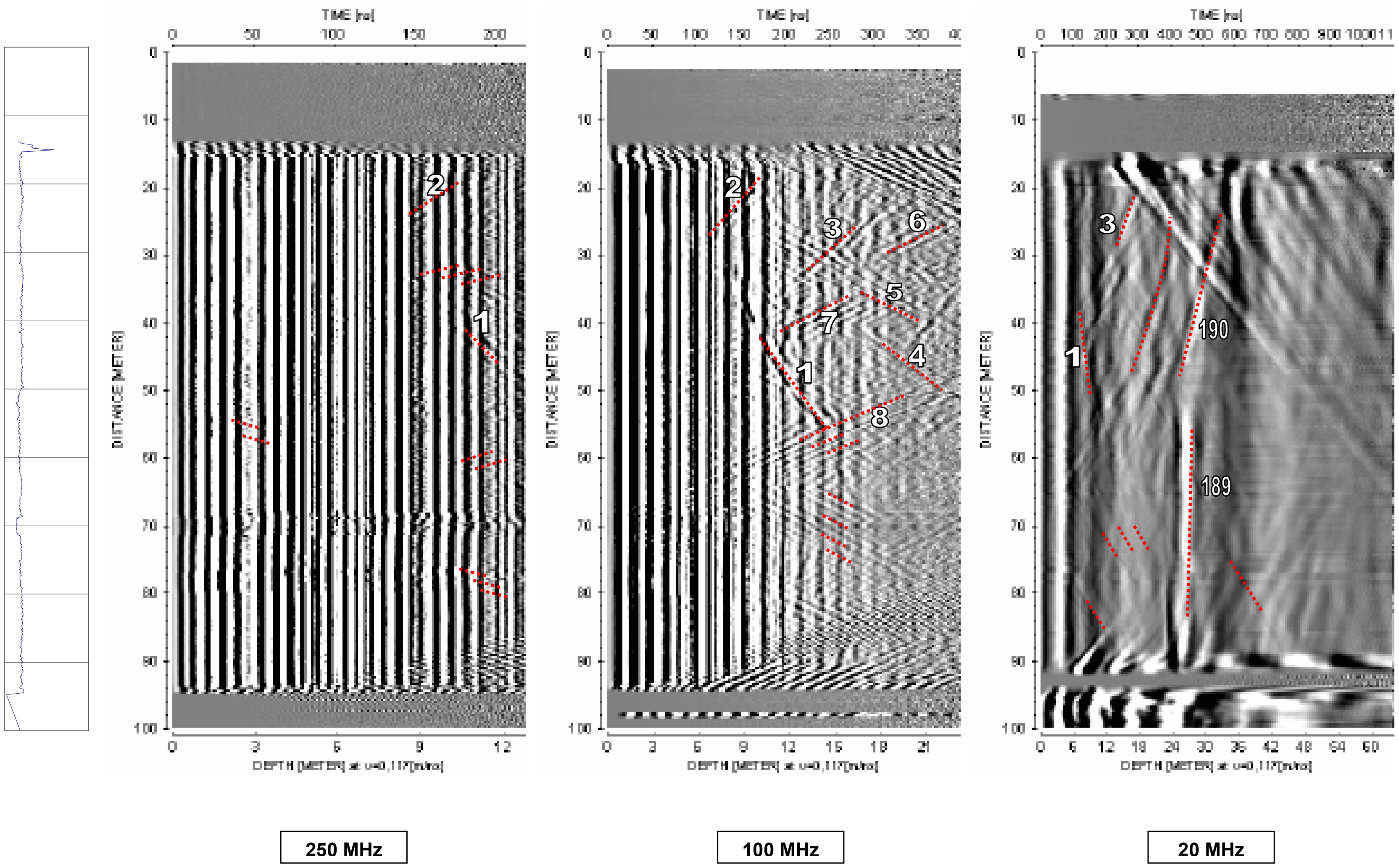
Figure 5-4. *Example from section were the automatic iris function changes the colors on the images.*

References

/1/ **Gustafsson J, Gustafsson C, 2005.** Oskarshamn site investigation. RAMAC and BIPS logging in boreholes KLX07A, KLX07B, HLX34 and HLX35 and deviation logging in boreholes KLX07B, HLX34 and HLX35. Svensk Kärnbränslehantering AB, SKB P-05-231.

Radar logging in KLX11A, 0 to 990 m, dipole antennas 250, 100 and 20 MHz

LAXEMAR KLX11A

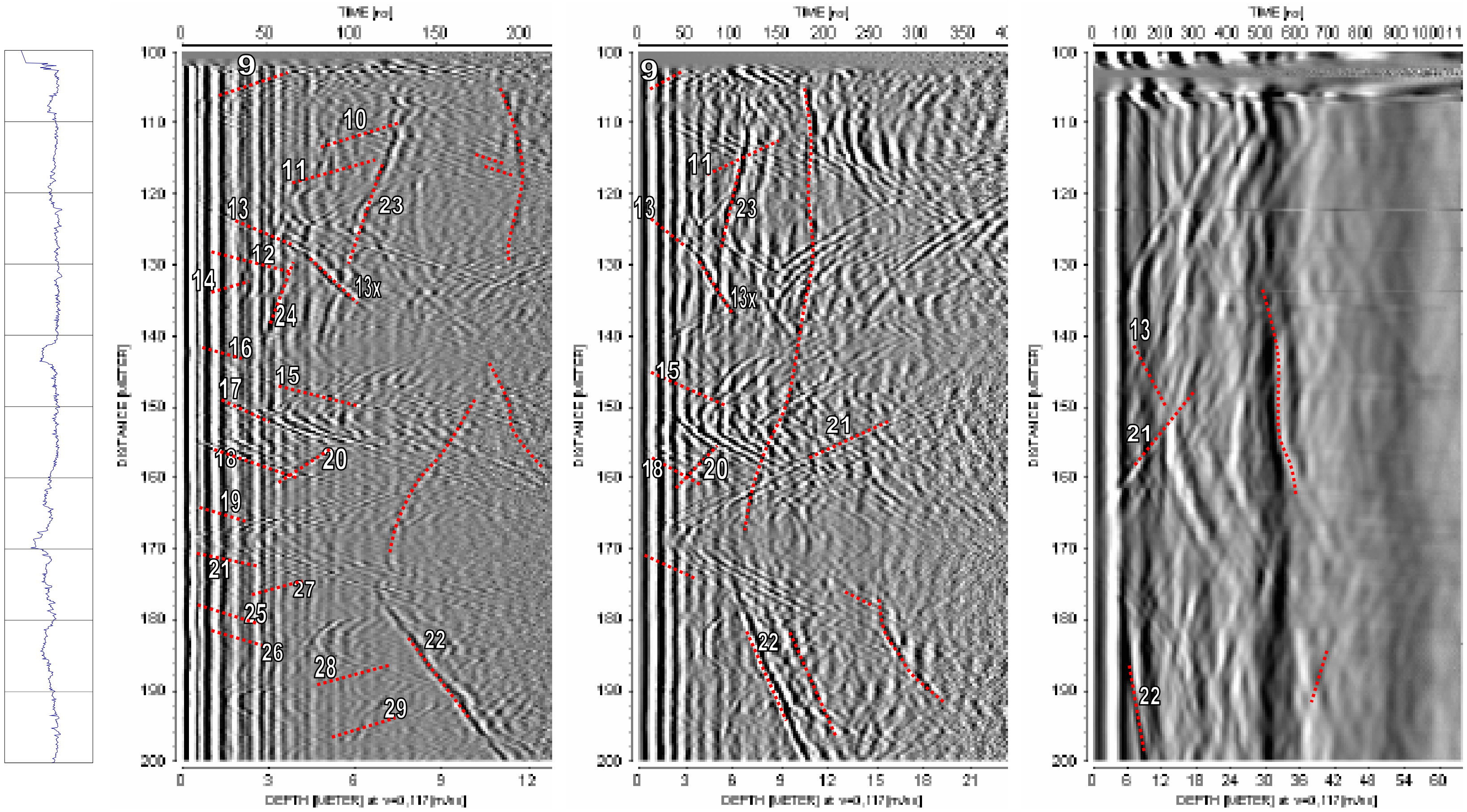


250 MHz

100 MHz

20 MHz

LAXEMAR KLX11A

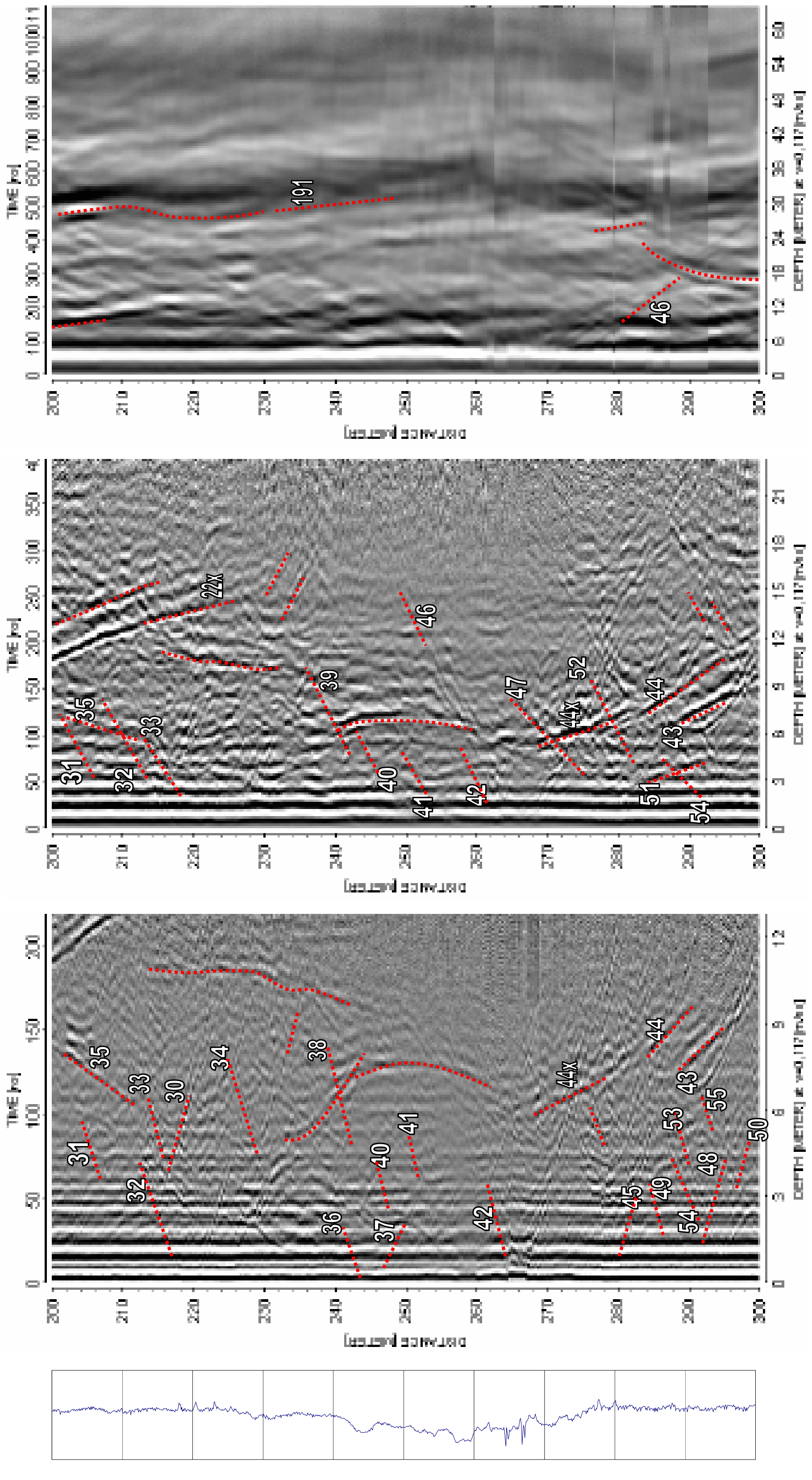


250 MHz

100 MHz

20 MHz

LAXEMAR KLX11A

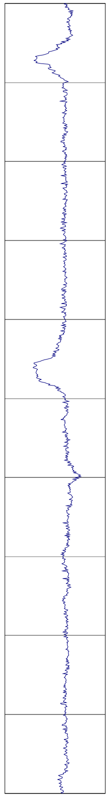


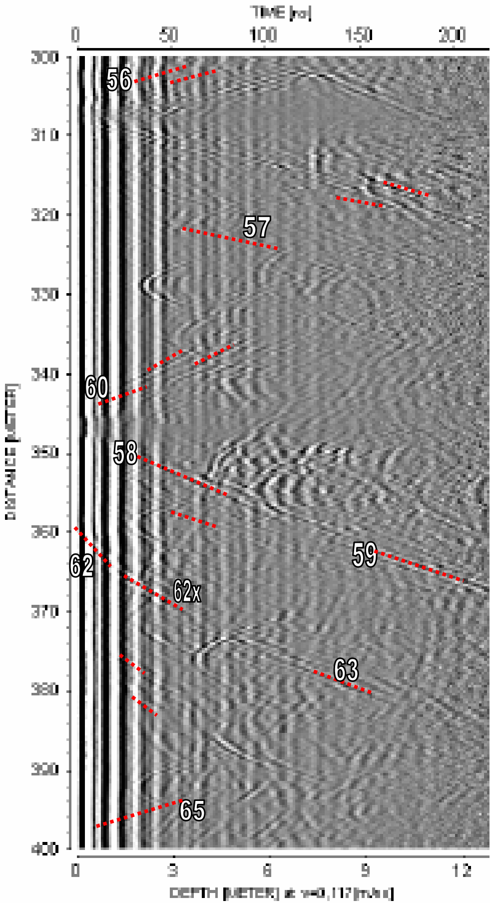
250 MHz

100 MHz

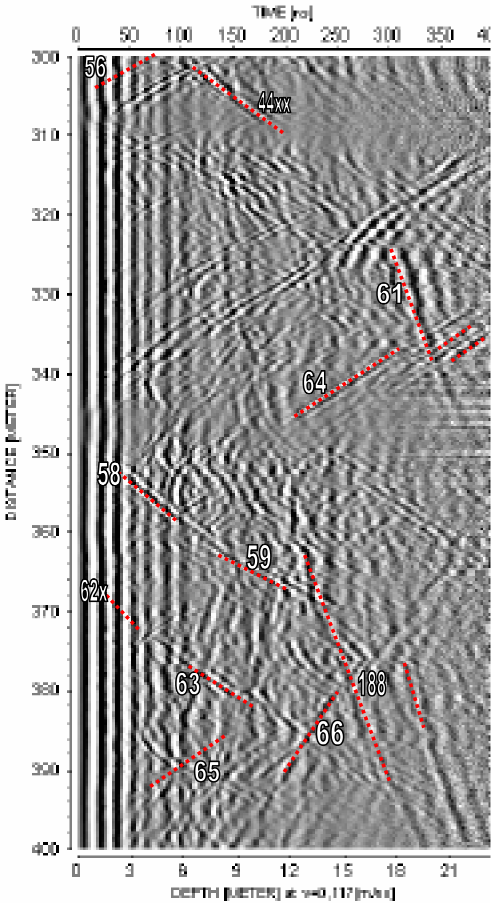
20 MHz

LAXEMAR KLX11A

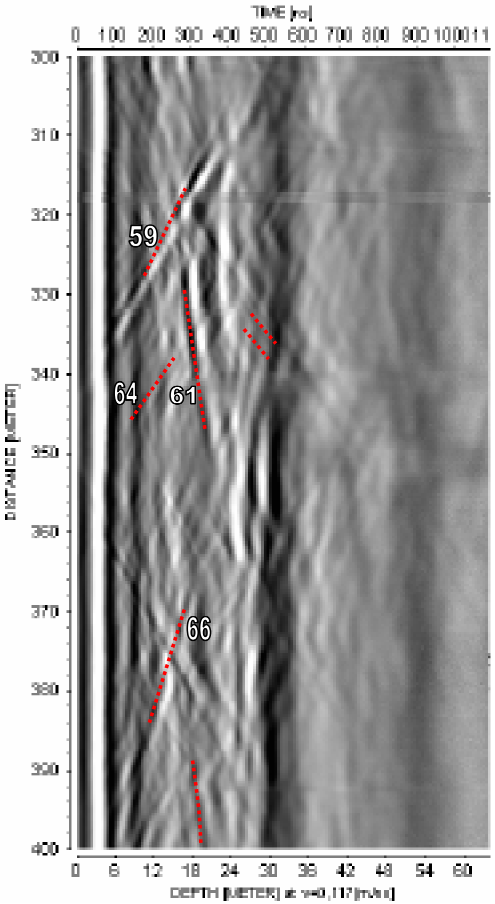




250 MHz

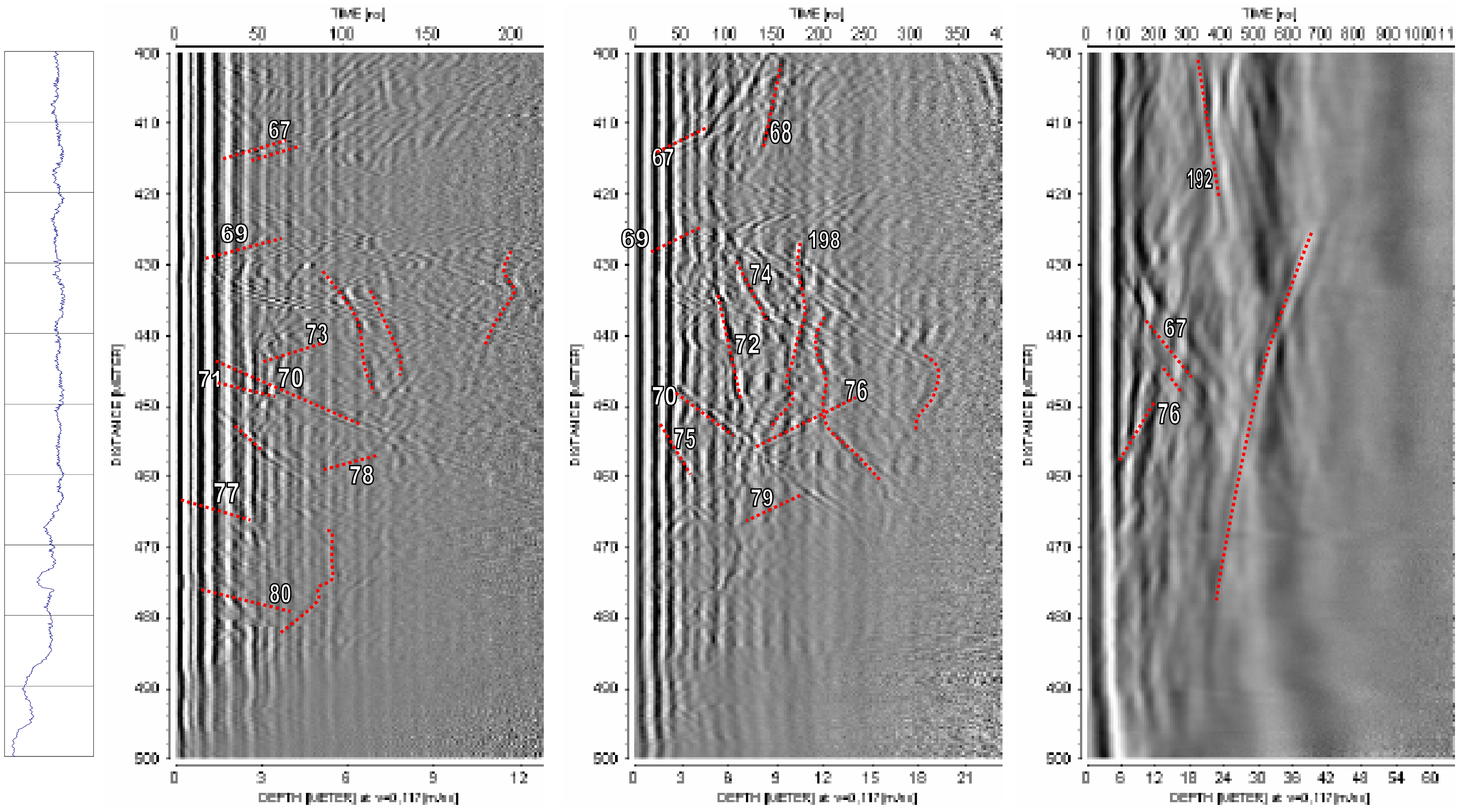


100 MHz



20 MHz

LAXEMAR KLX11A

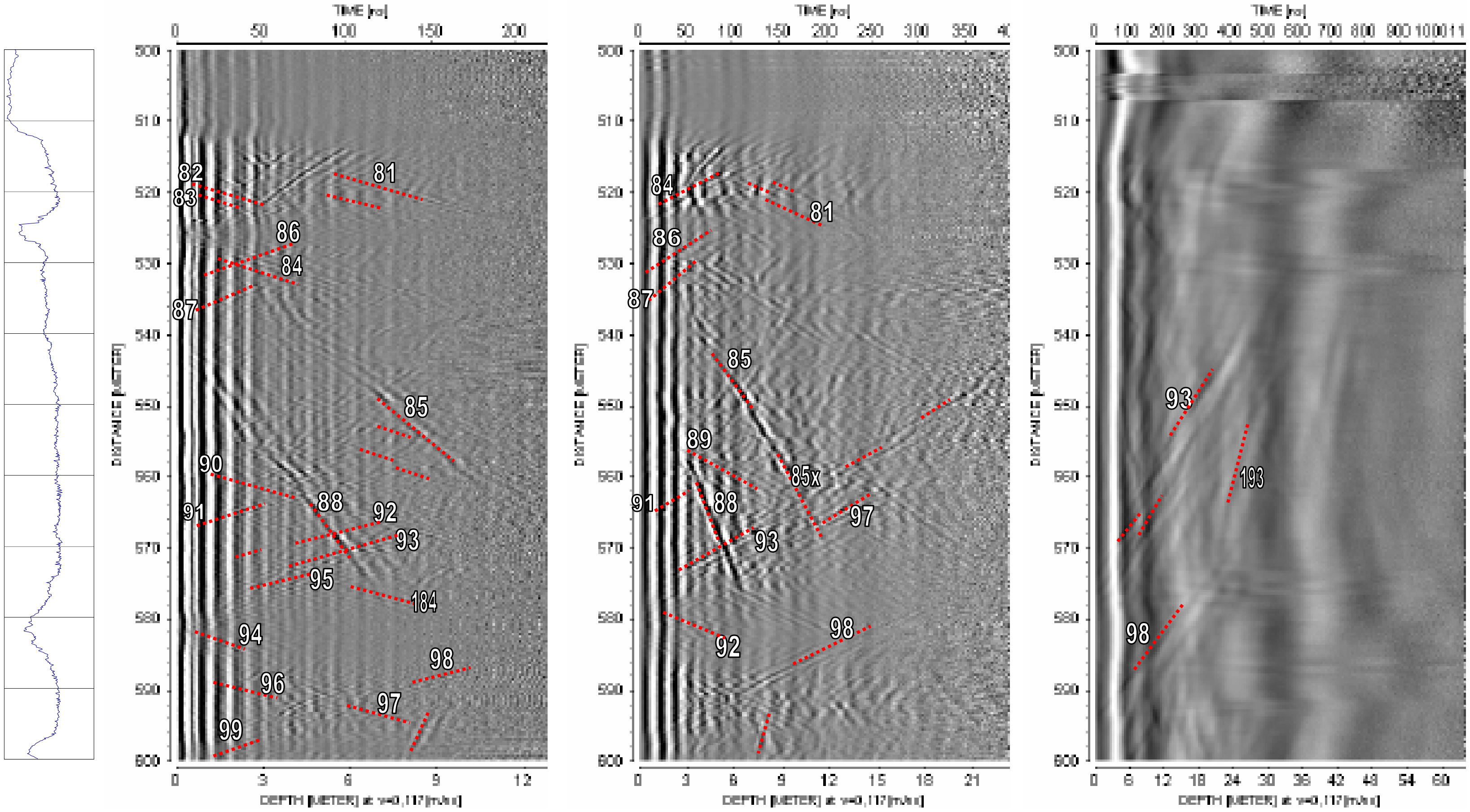


250 MHz

100 MHz

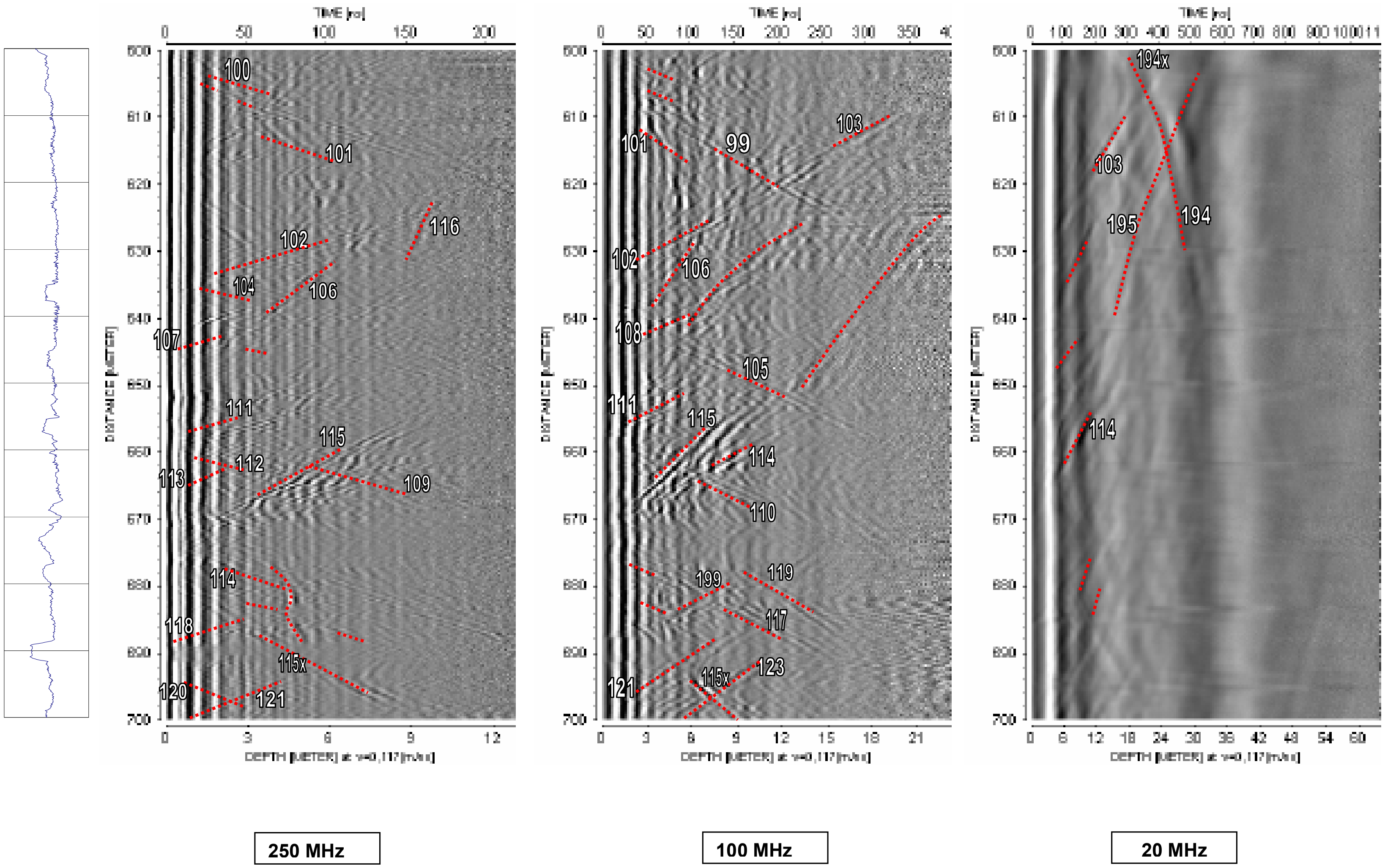
20 MHz

LAXEMAR KLX11A

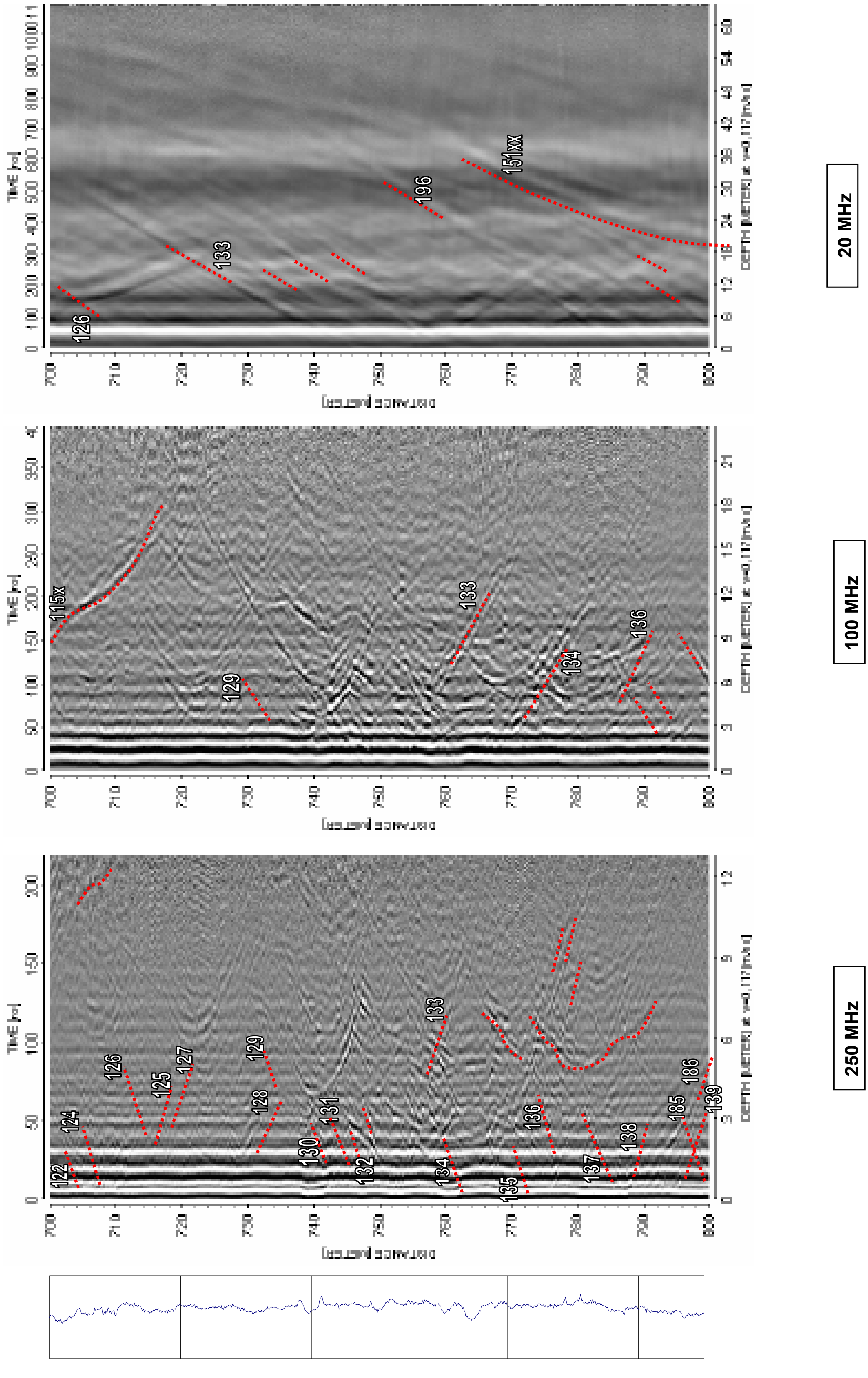


250 MHz **100 MHz** **20 MHz**

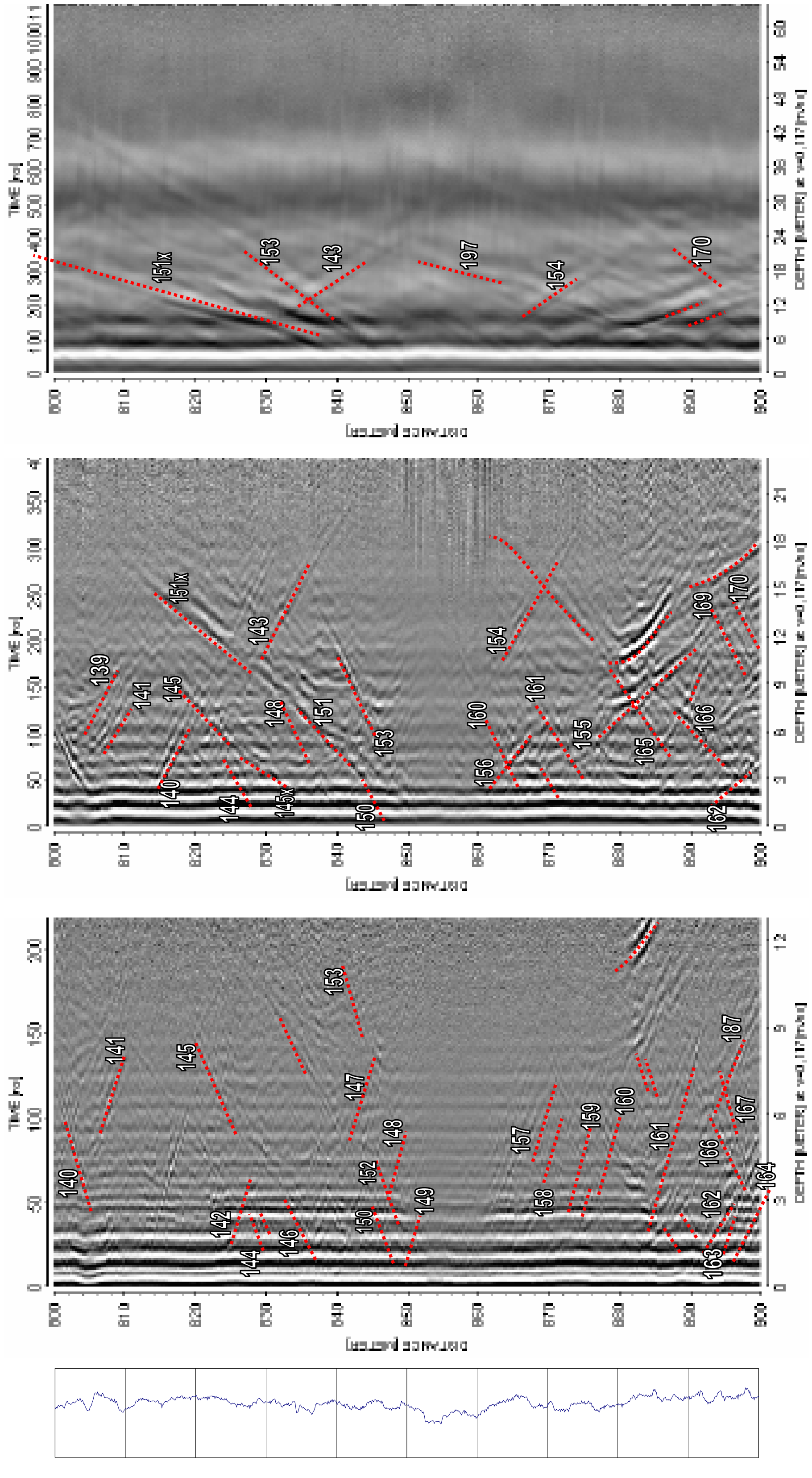
LAXEMAR KLX11A



LAXEMAR KLX11A



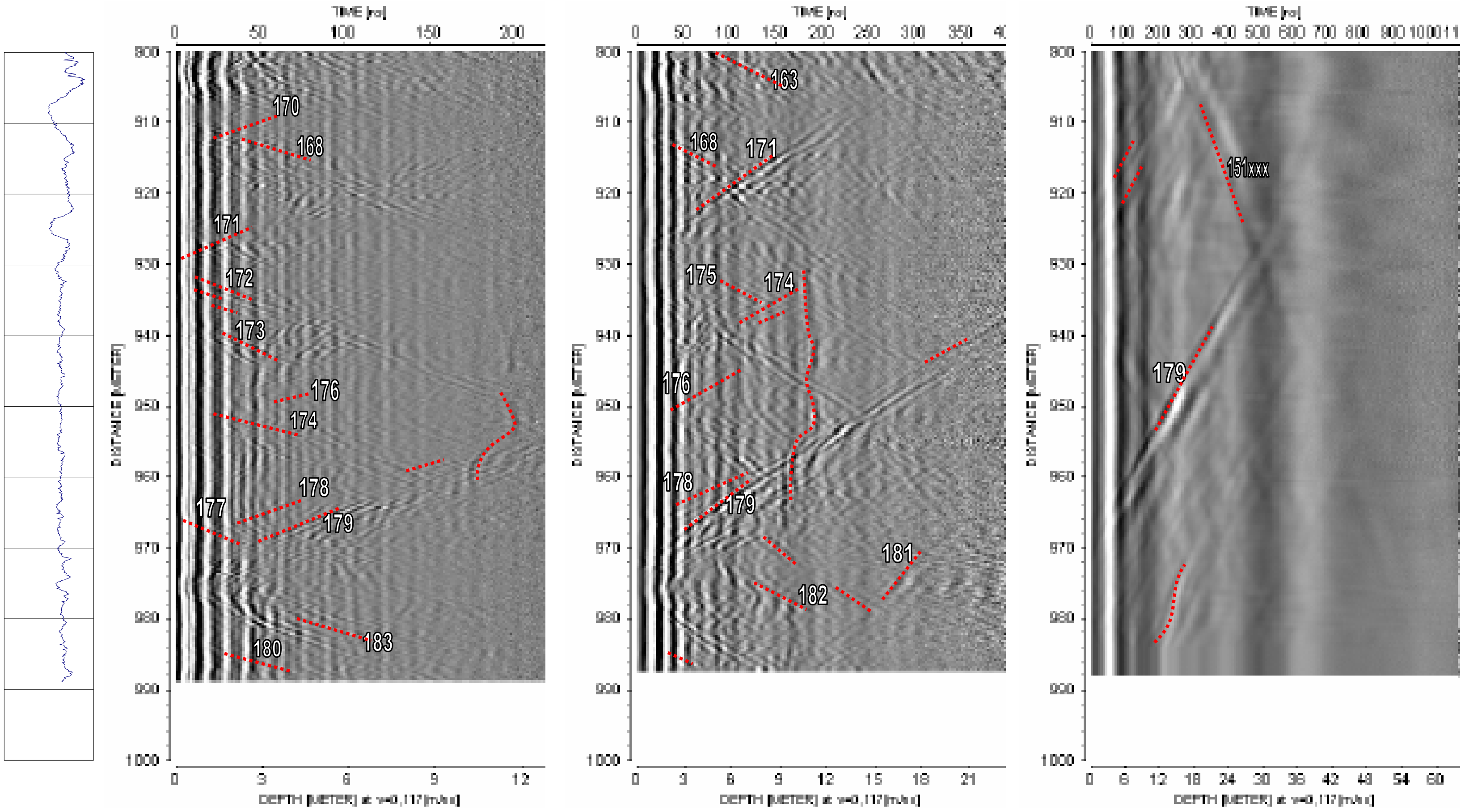
LAXEMAR KLX11A



250 MHz

100 MHz

LAXEMAR KLX11A



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

Appendix 2

BIPS logging in KLX11A, 12 to 989 m

Project name: Laxemar

Image file : c:\work\klx11a\klx11a_1.bip

BDT file : c:\work\klx11a\klx11a_1.bdt

Locality : LAXEMAR

Bore hole number : KLX11A

Date : 06/04/04

Time : 19:18:00

Depth range : 12.000 - 96.111 m

Azimuth : 90

Inclination : -76

Diameter : 197.0 mm

Magnetic declination : 0.0

Span : 4

Scan interval : 0.25

Scan direction : To bottom

Scale : 1/25

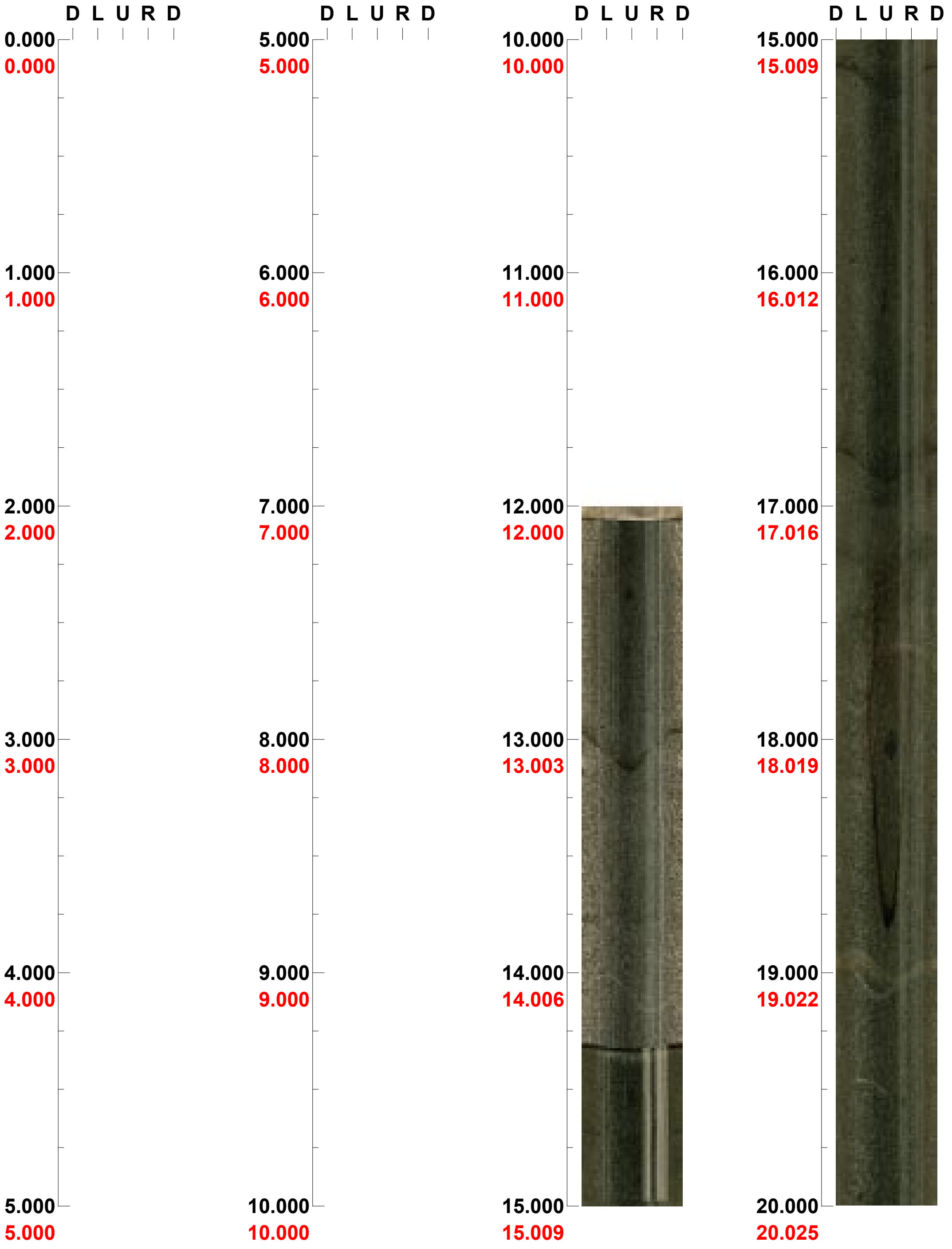
Aspect ratio : 70 %

Pages : 5

Color : 🟥 🟩 🟦
+0 +0 +0

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 0.000 - 20.000 m



(1 / 5) **Scale: 1/25** **Aspect ratio: 70 %**

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 20.000 - 40.000 m

(2 / 5) **Scale: 1/25** **Aspect ratio: 70 %**

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 40.000 - 60.000 m

(3 / 5) **Scale: 1/25** **Aspect ratio: 70 %**

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 60.000 - 80.000 m

(4 / 5) **Scale: 1/25** **Aspect ratio: 70 %**

Project name: Laxemar

Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 80.000 - 96.111 m

(5 / 5) **Scale: 1/25** **Aspect ratio: 70 %**

Project name: Laxemar

Image file : c:\work\klx11a\klx11a_2.bip

BDT file : c:\work\klx11a\klx11a_2.bdt

Locality : LAXEMAR

Bore hole number : KLX11A

Date : 06/04/05

Time : 08:34:00

Depth range : 96.000 - 989.350 m

Azimuth : 90

Inclination : -76

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 : 26

Color : 🟥 🟩 🟦
+0 +0 +0

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 80.000 - 100.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 100.000 - 120.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 120.000 - 140.000 m

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

Project name: Laxemar

Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 140.000 - 160.000 m

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

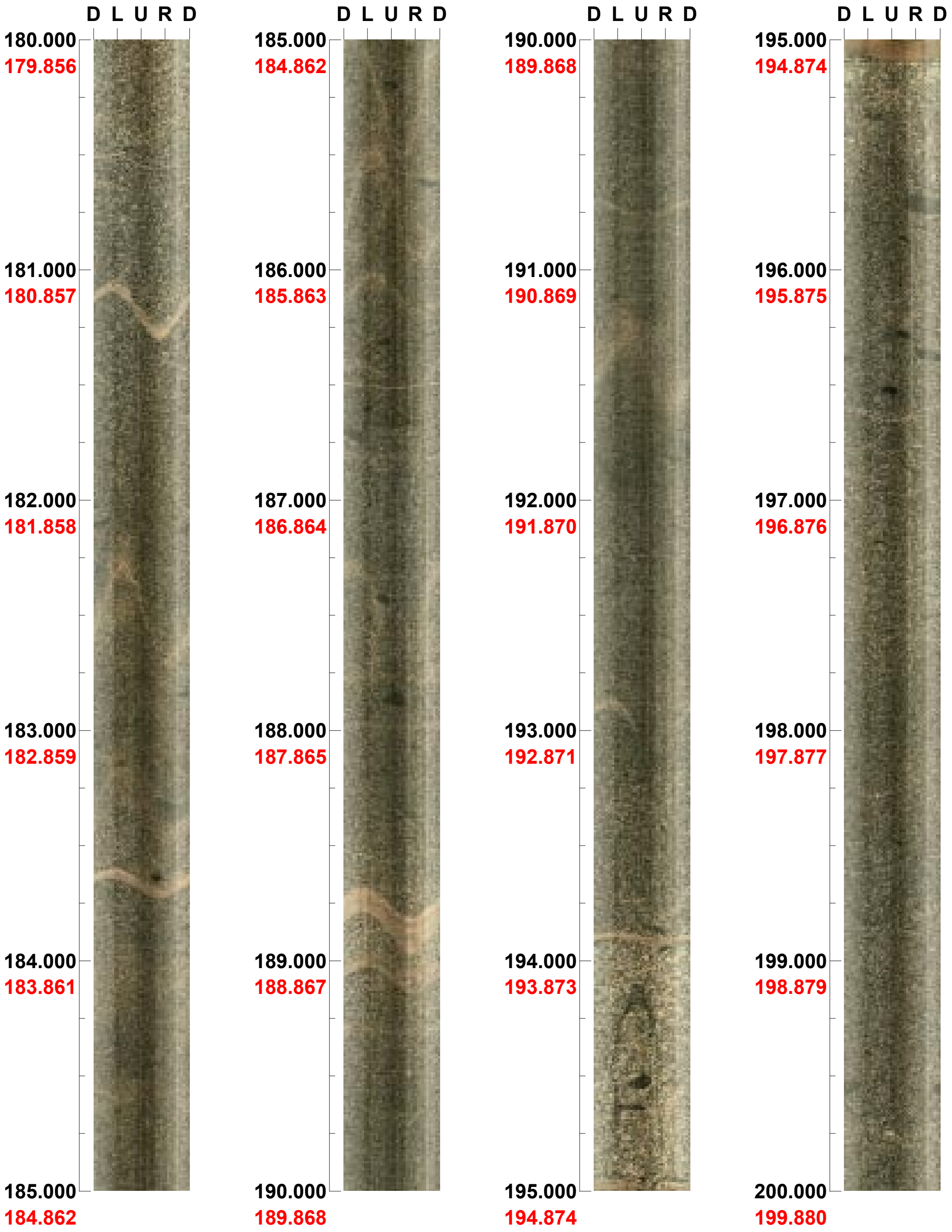
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 160.000 - 180.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 180.000 - 200.000 m



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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 200.000 - 220.000 m

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

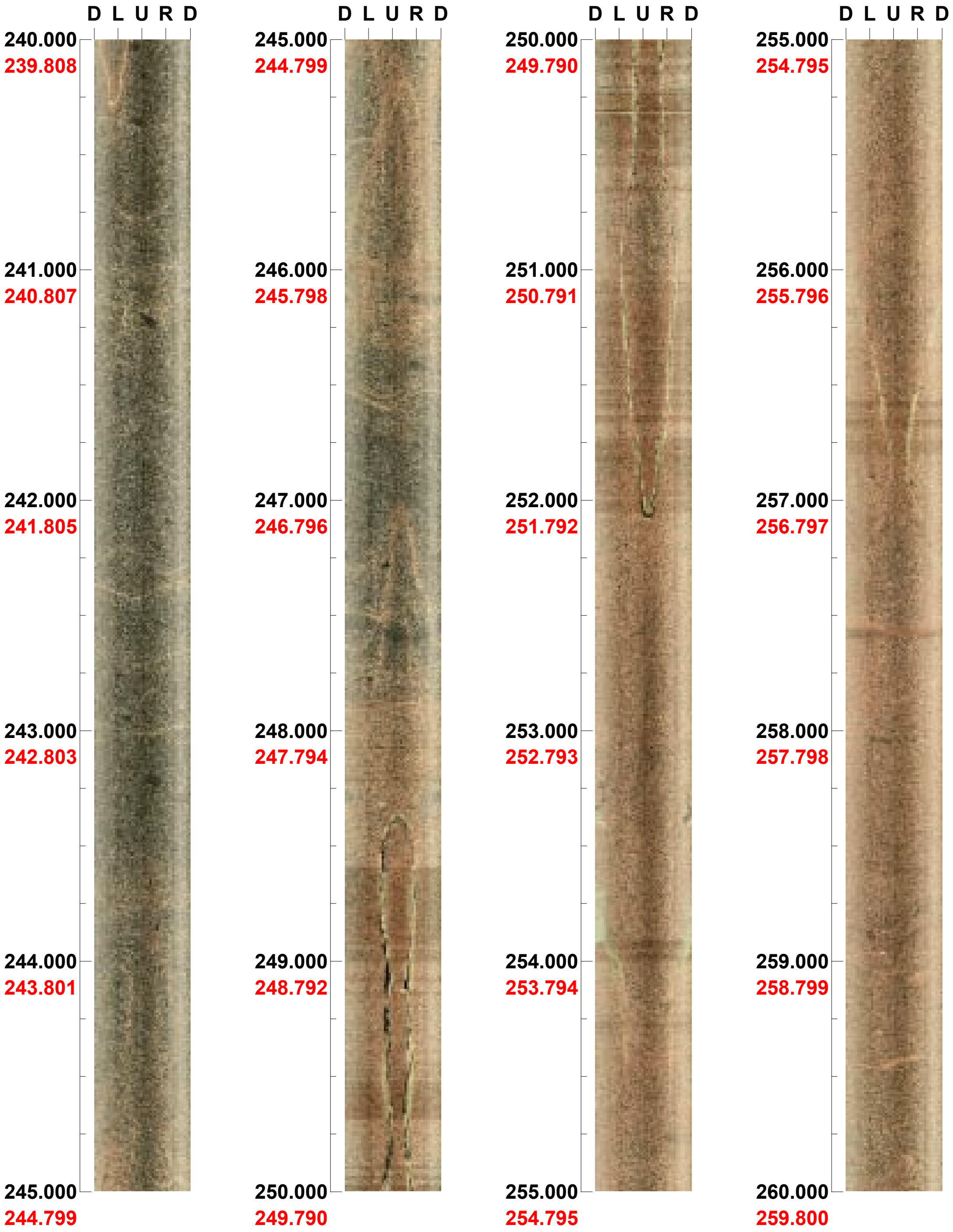
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 220.000 - 240.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 240.000 - 260.000 m



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

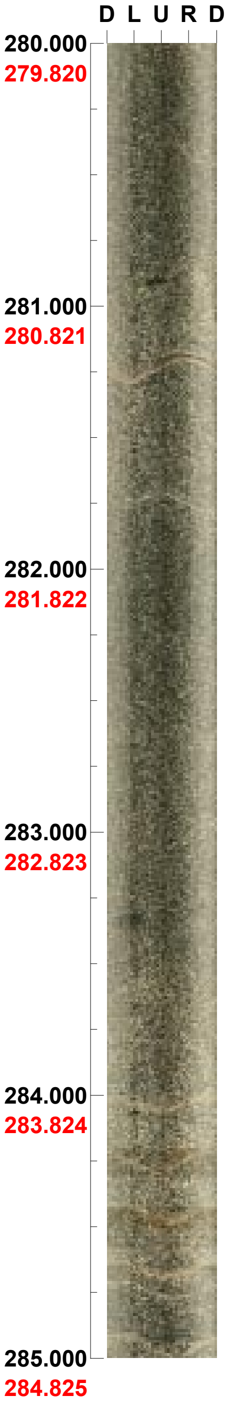
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

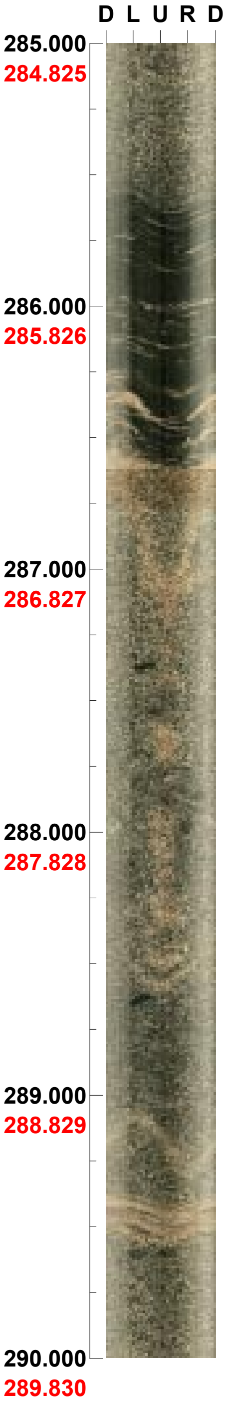
Depth range: 260.000 - 280.000 m

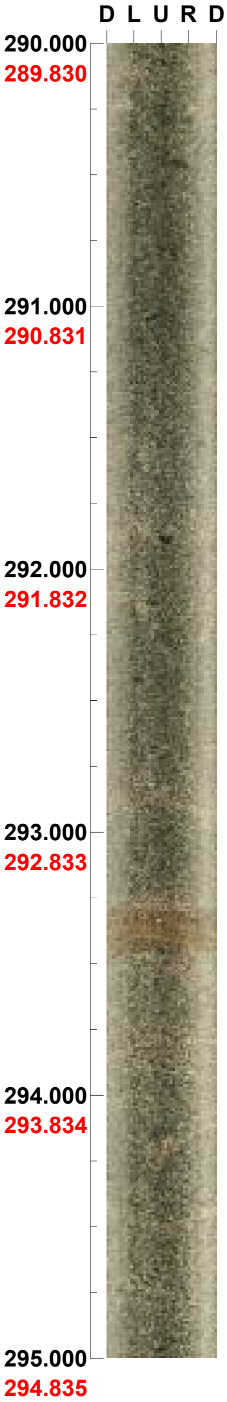
(10 / 26) Scale: 1/25 Aspect ratio: 175 %

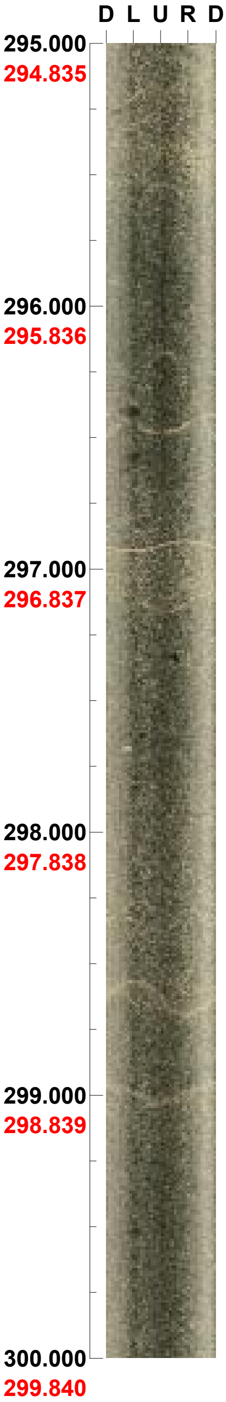
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 280.000 - 300.000 m









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

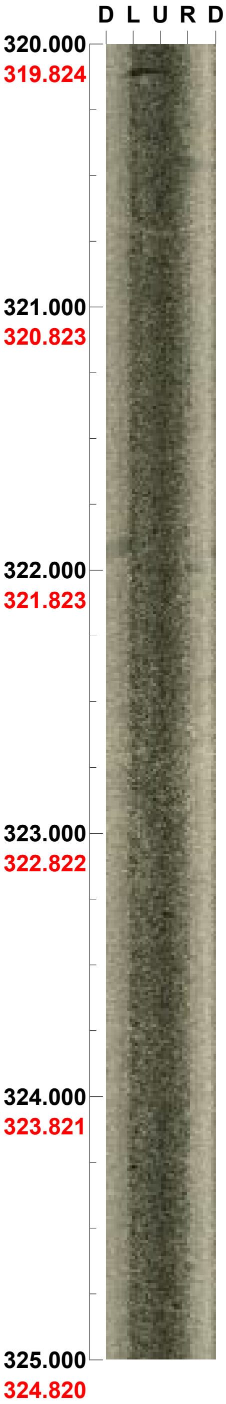
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

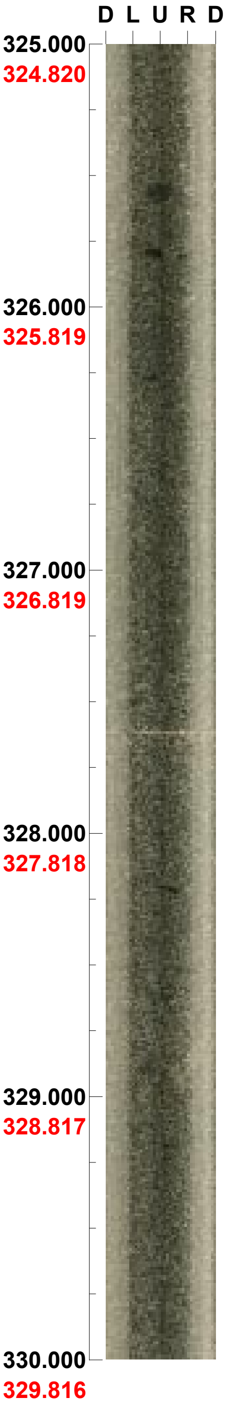
Depth range: 300.000 - 320.000 m

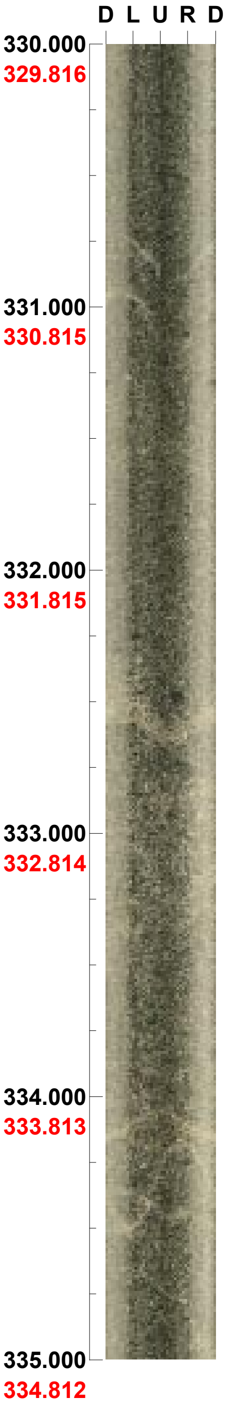
(12 / 26) **Scale: 1/25** **Aspect ratio: 175 %**

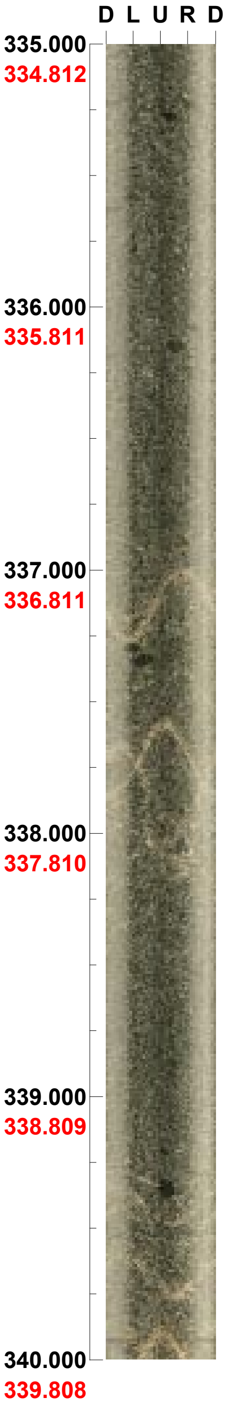
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 320.000 - 340.000 m









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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 340.000 - 360.000 m

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

Project name: Laxemar

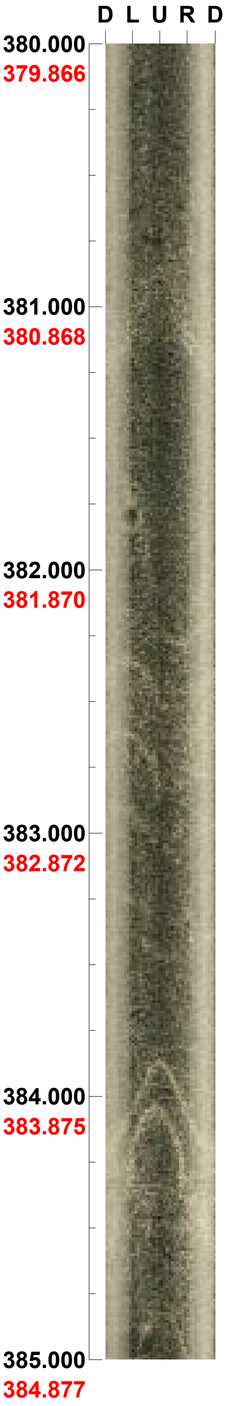
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

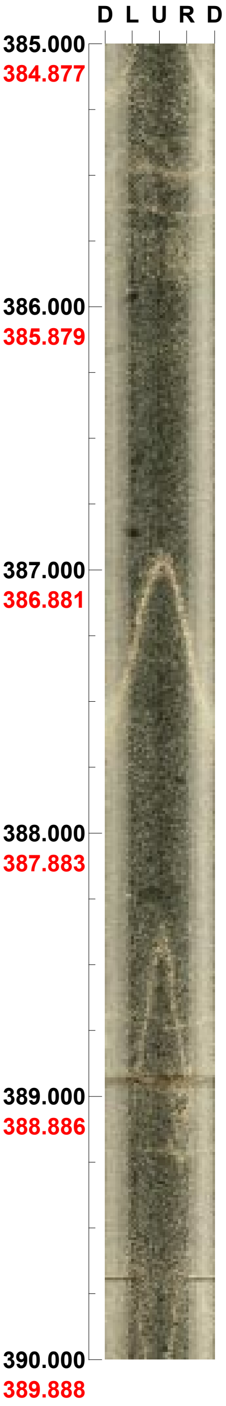
Depth range: 360.000 - 380.000 m

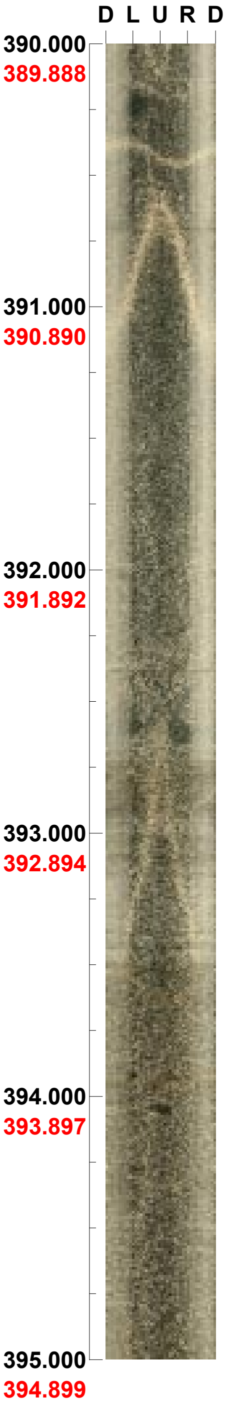
(15 / 26) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 380.000 - 400.000 m







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

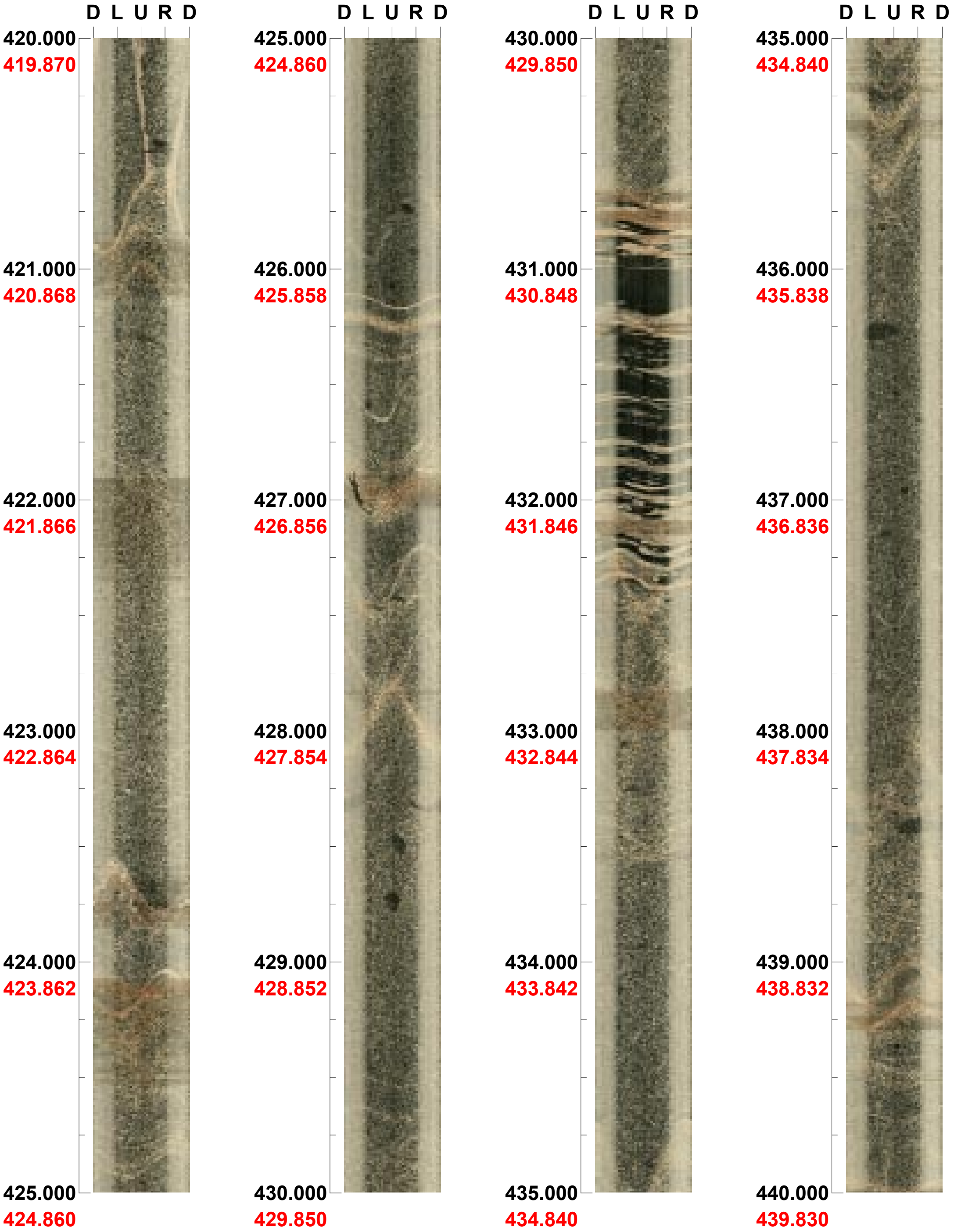
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 400.000 - 420.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 420.000 - 440.000 m



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

Project name: Laxemar

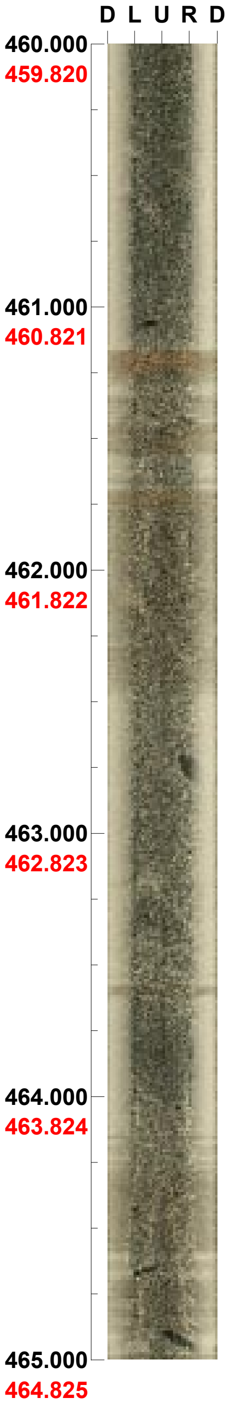
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

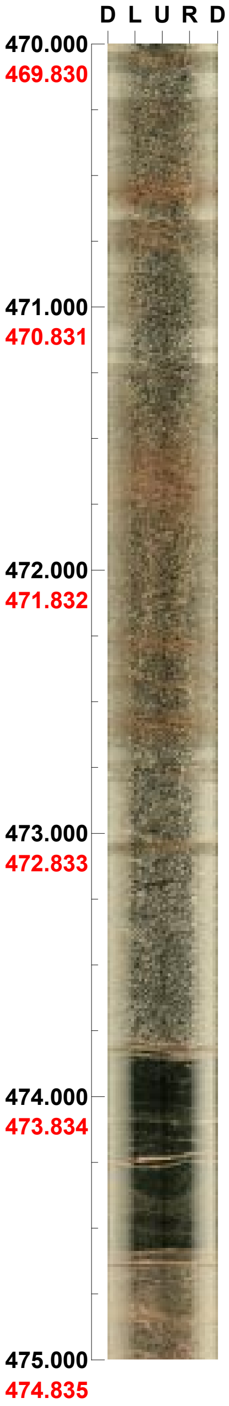
Depth range: 440.000 - 460.000 m

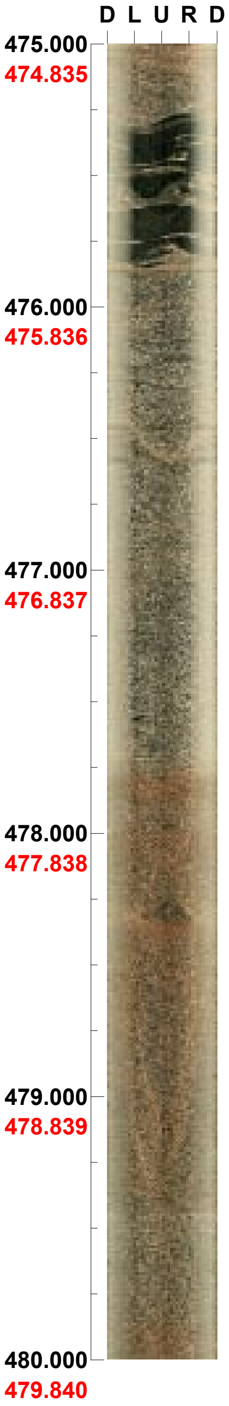
(19 / 26) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 460.000 - 480.000 m







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

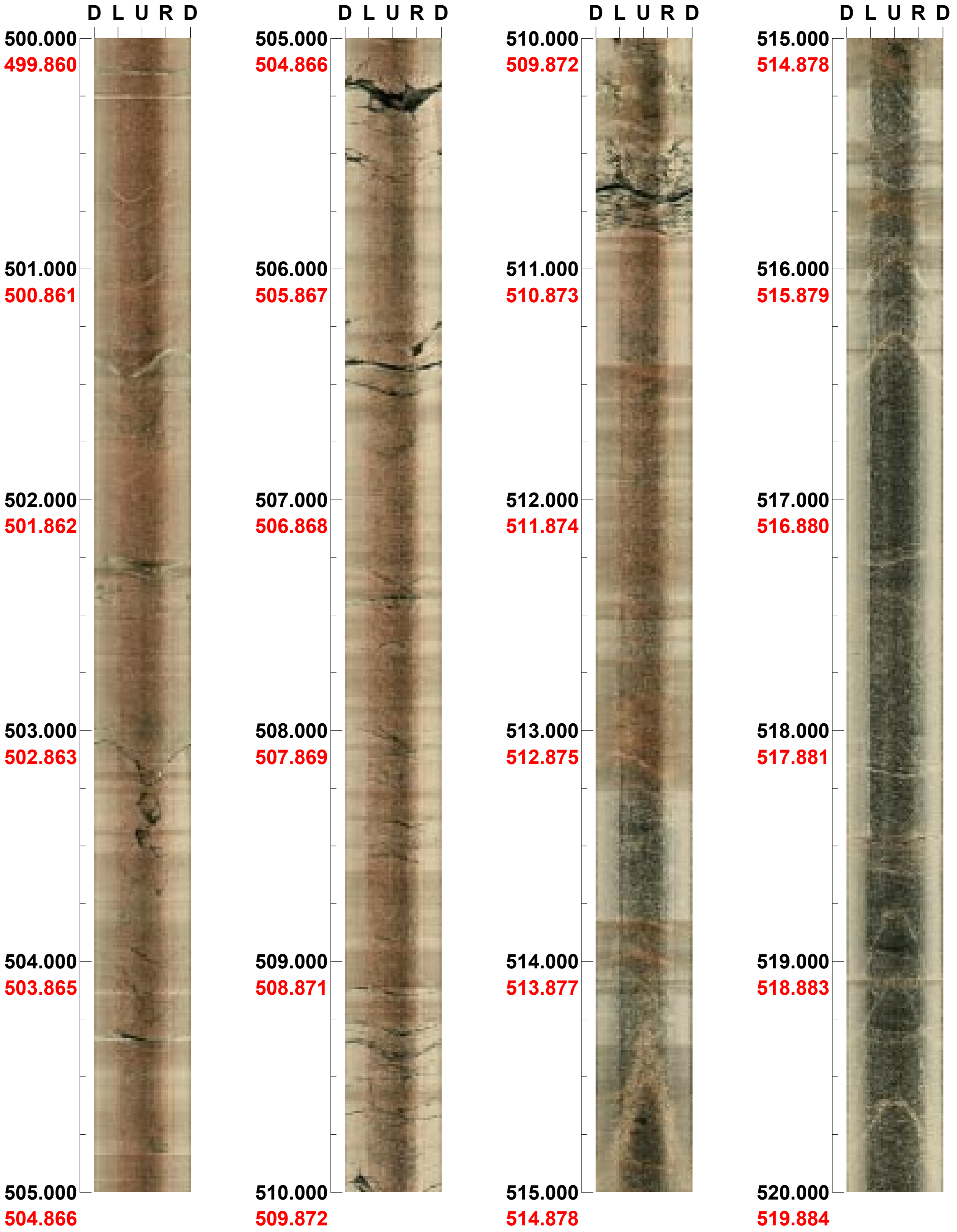
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 480.000 - 500.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 500.000 - 520.000 m



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

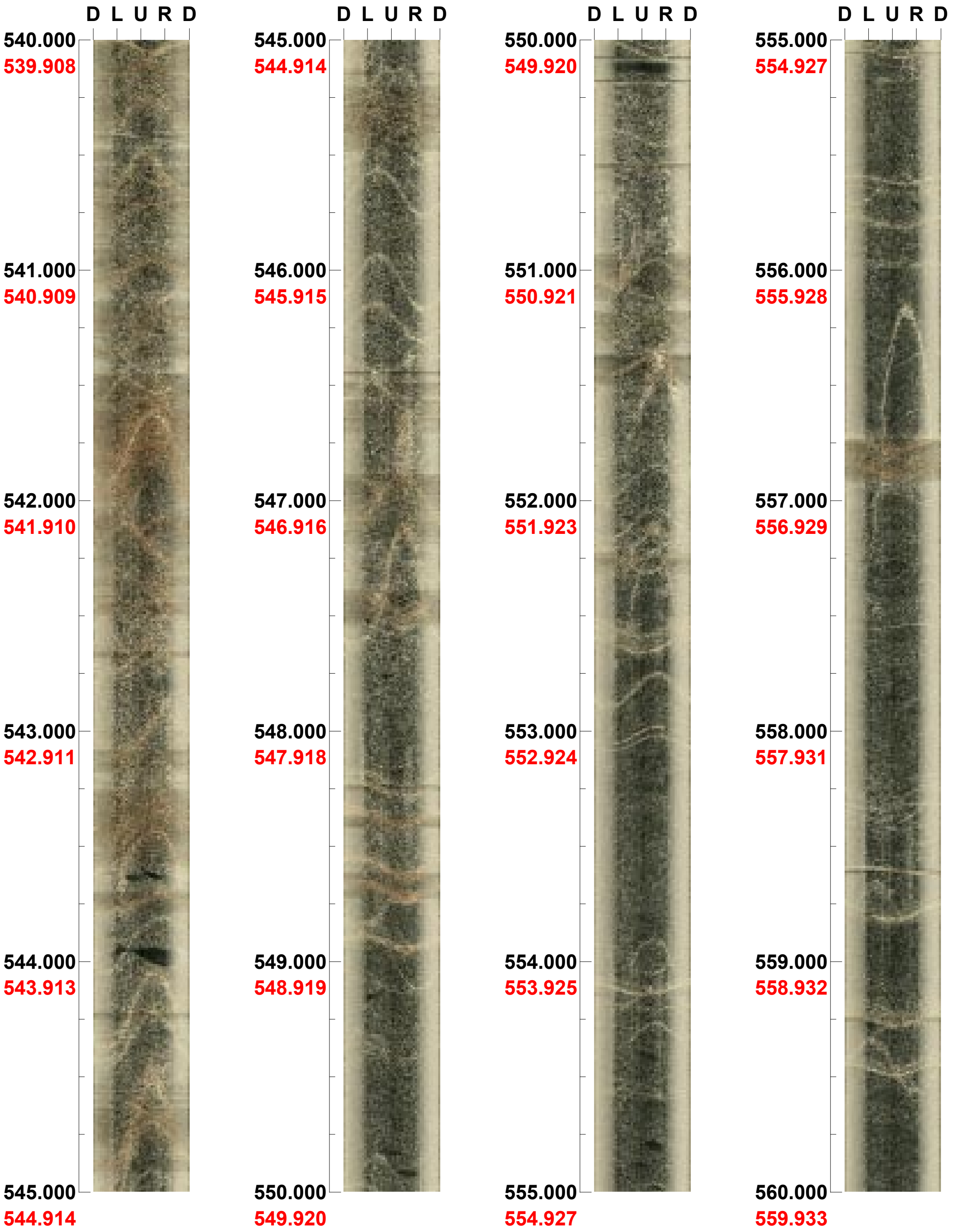
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 520.000 - 540.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 540.000 - 560.000 m

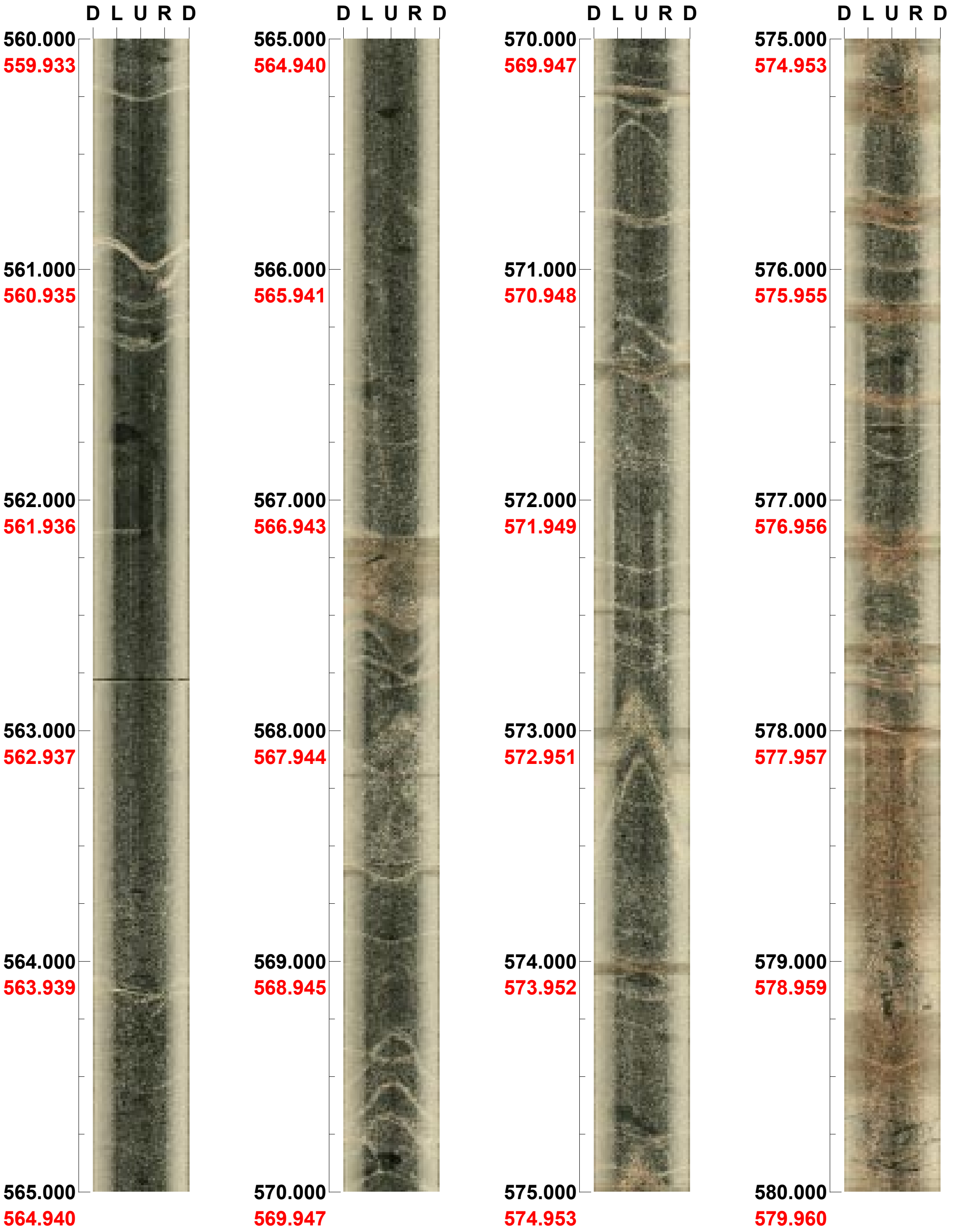


(24 / 26) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Laxemar

Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

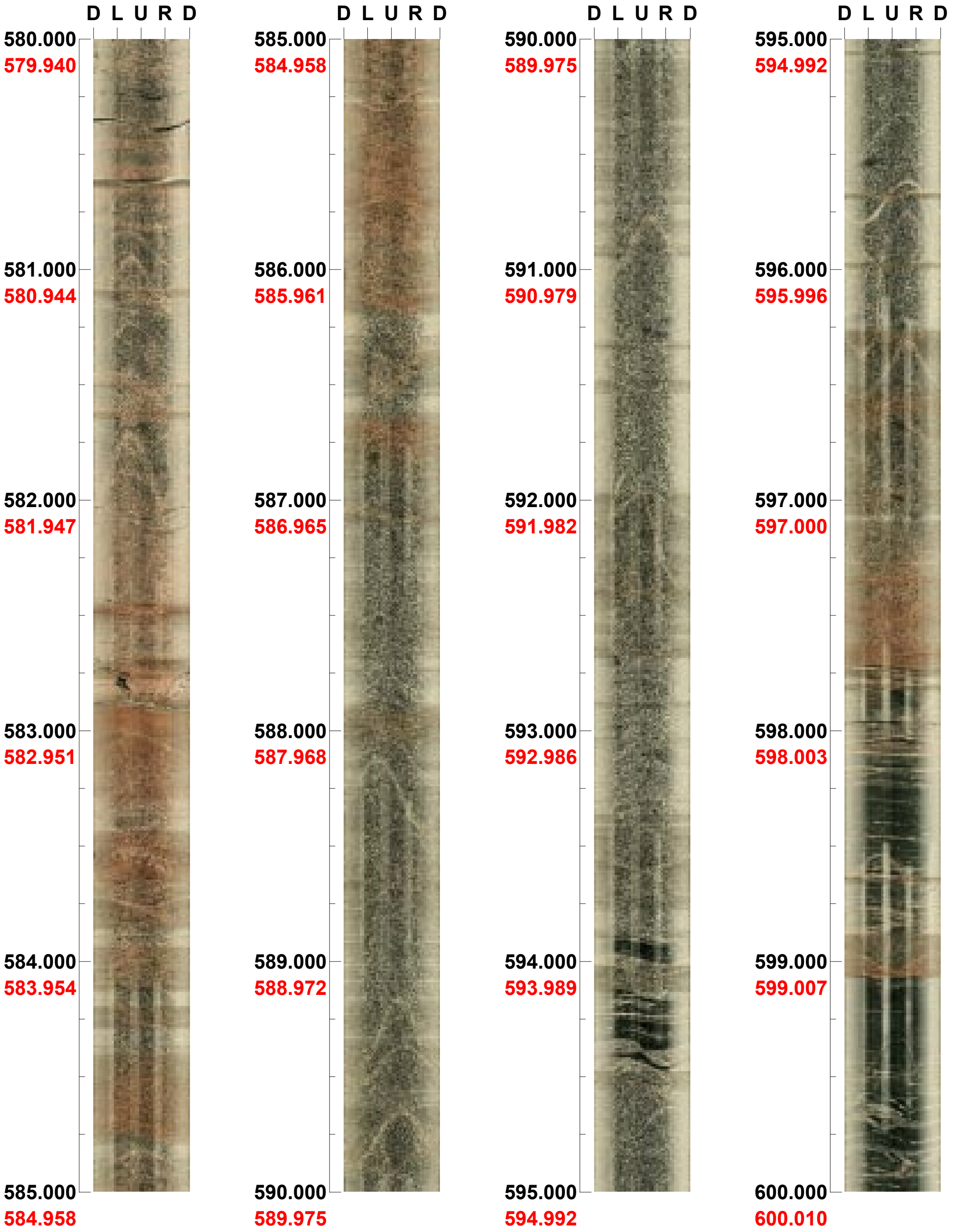
Depth range: 560.000 - 580.000 m



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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 580.000 - 600.000 m



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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 600.000 - 620.000 m

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

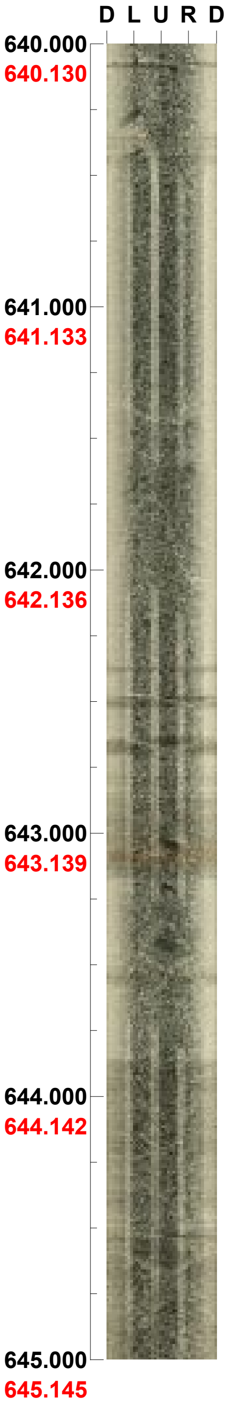
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

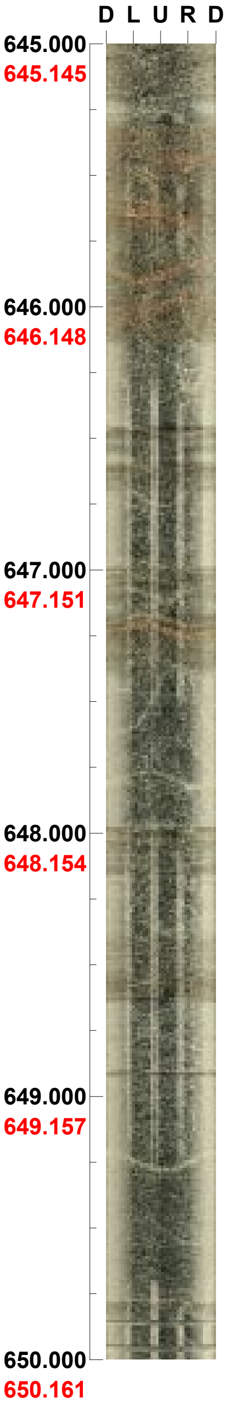
Depth range: 620.000 - 640.000 m

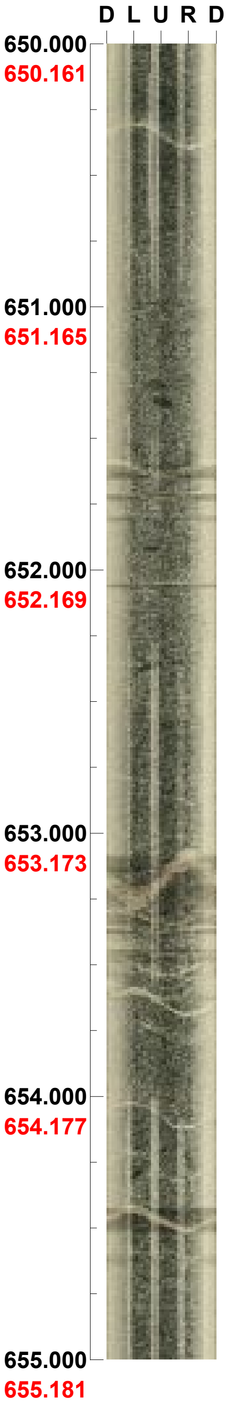
(3 / 21) **Scale: 1/25** **Aspect ratio: 175 %**

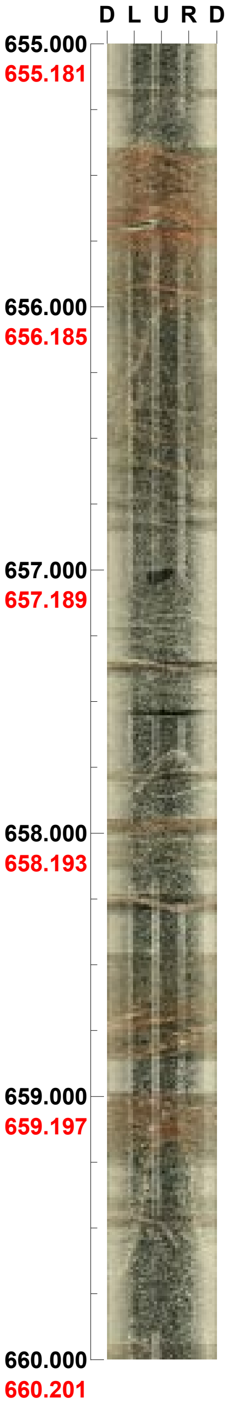
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 640.000 - 660.000 m









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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 660.000 - 680.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 680.000 - 700.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 700.000 - 720.000 m

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

Project name: Laxemar

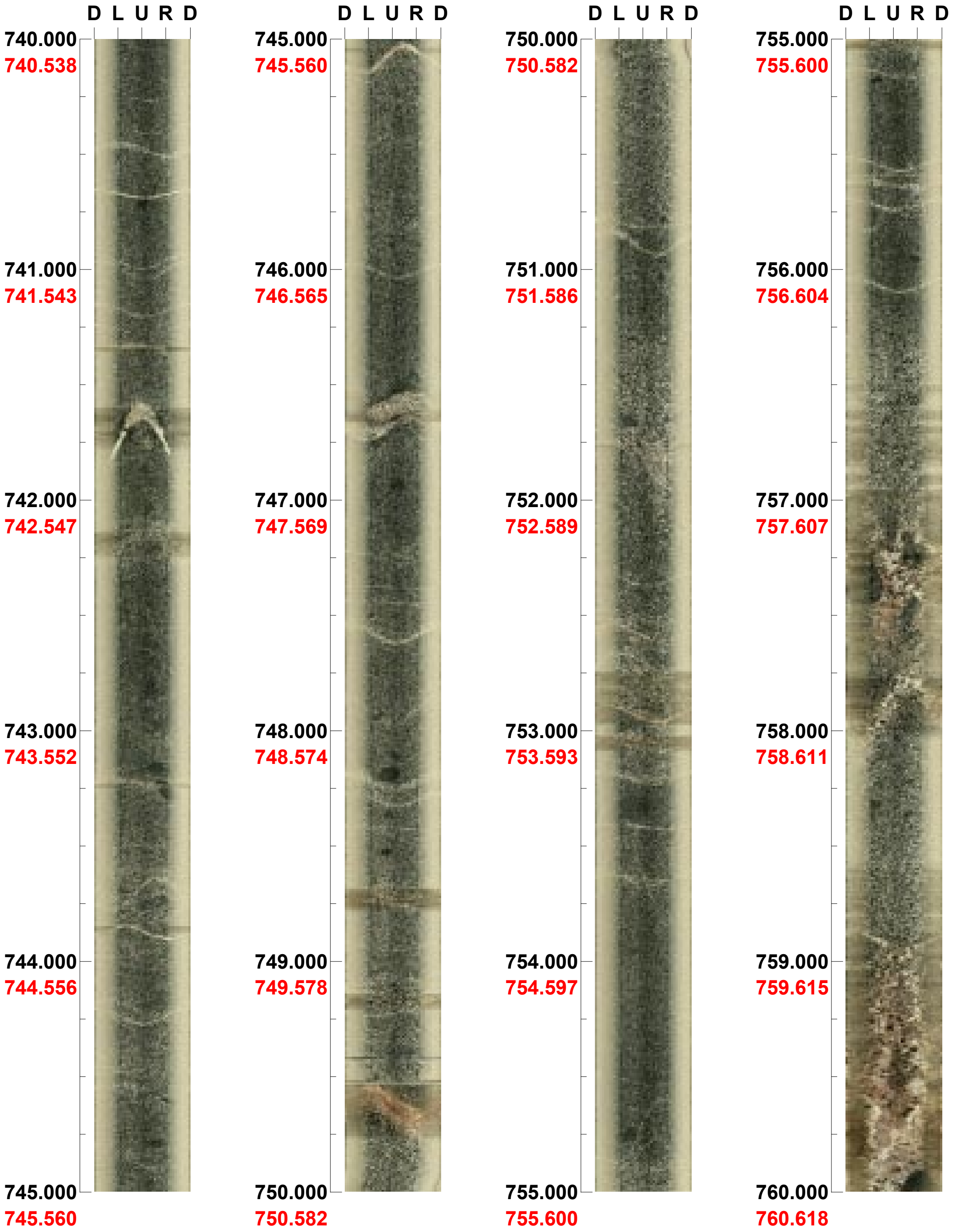
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 720.000 - 740.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

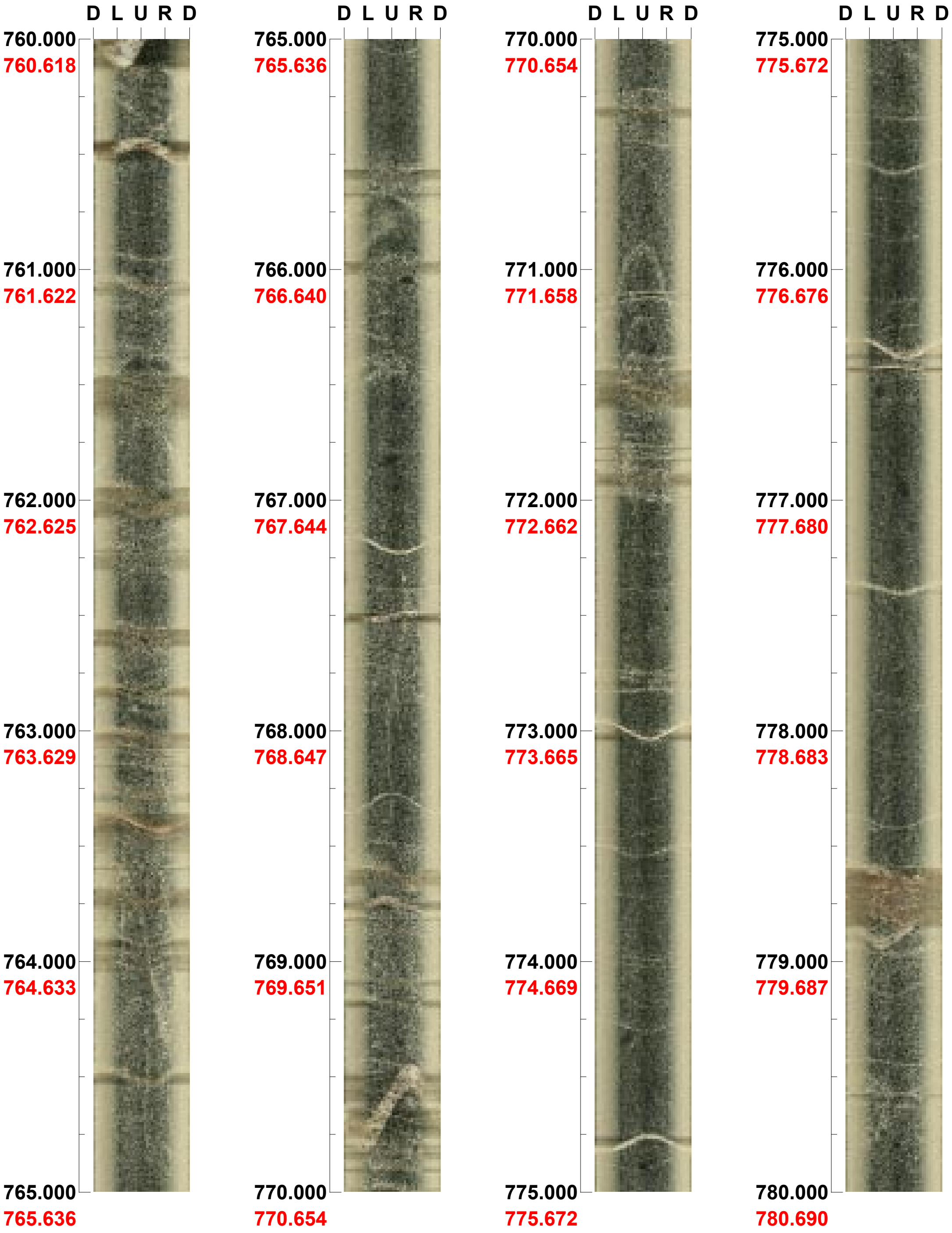
Depth range: 740.000 - 760.000 m



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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

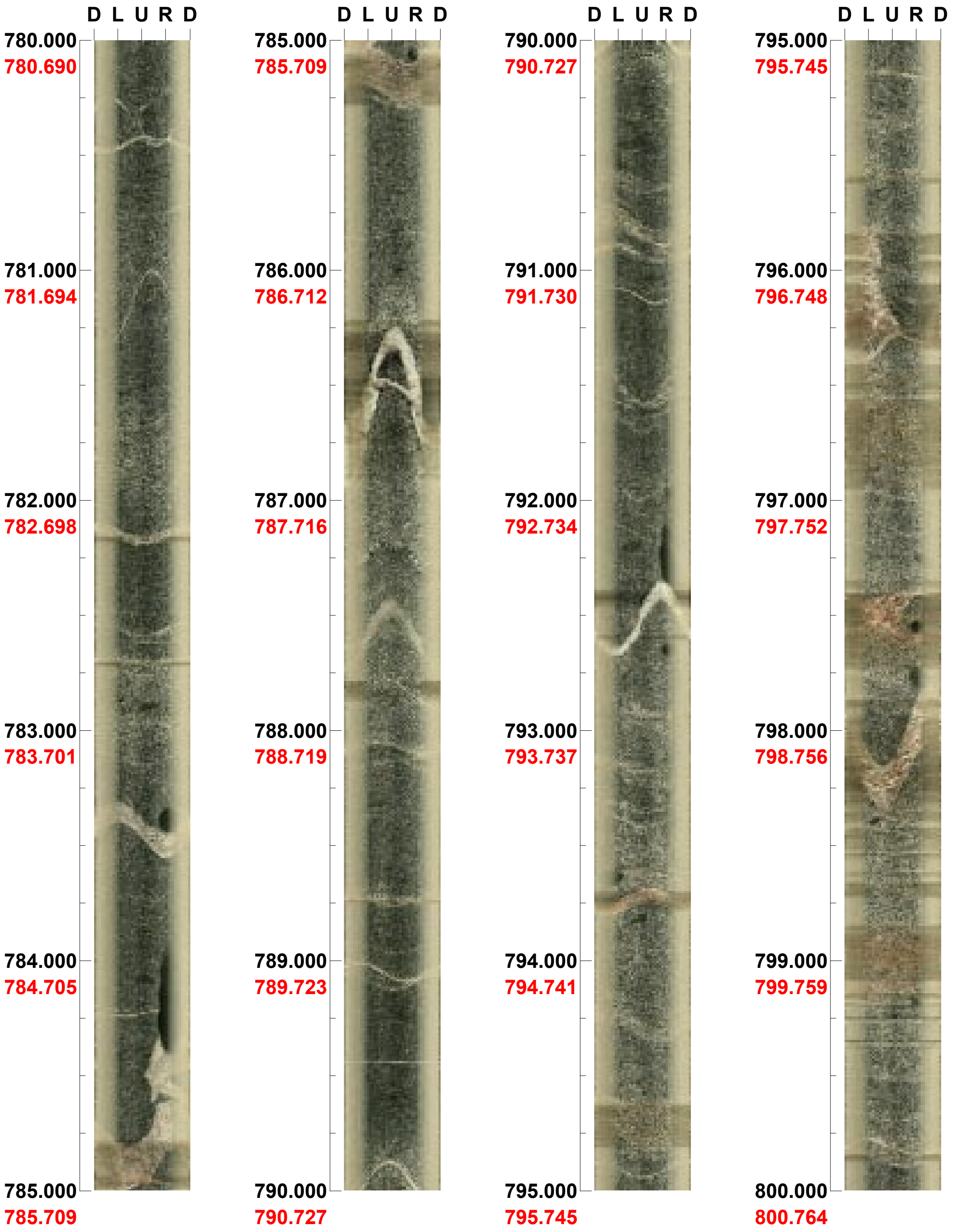
Depth range: 760.000 - 780.000 m



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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 780.000 - 800.000 m



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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 800.000 - 820.000 m

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

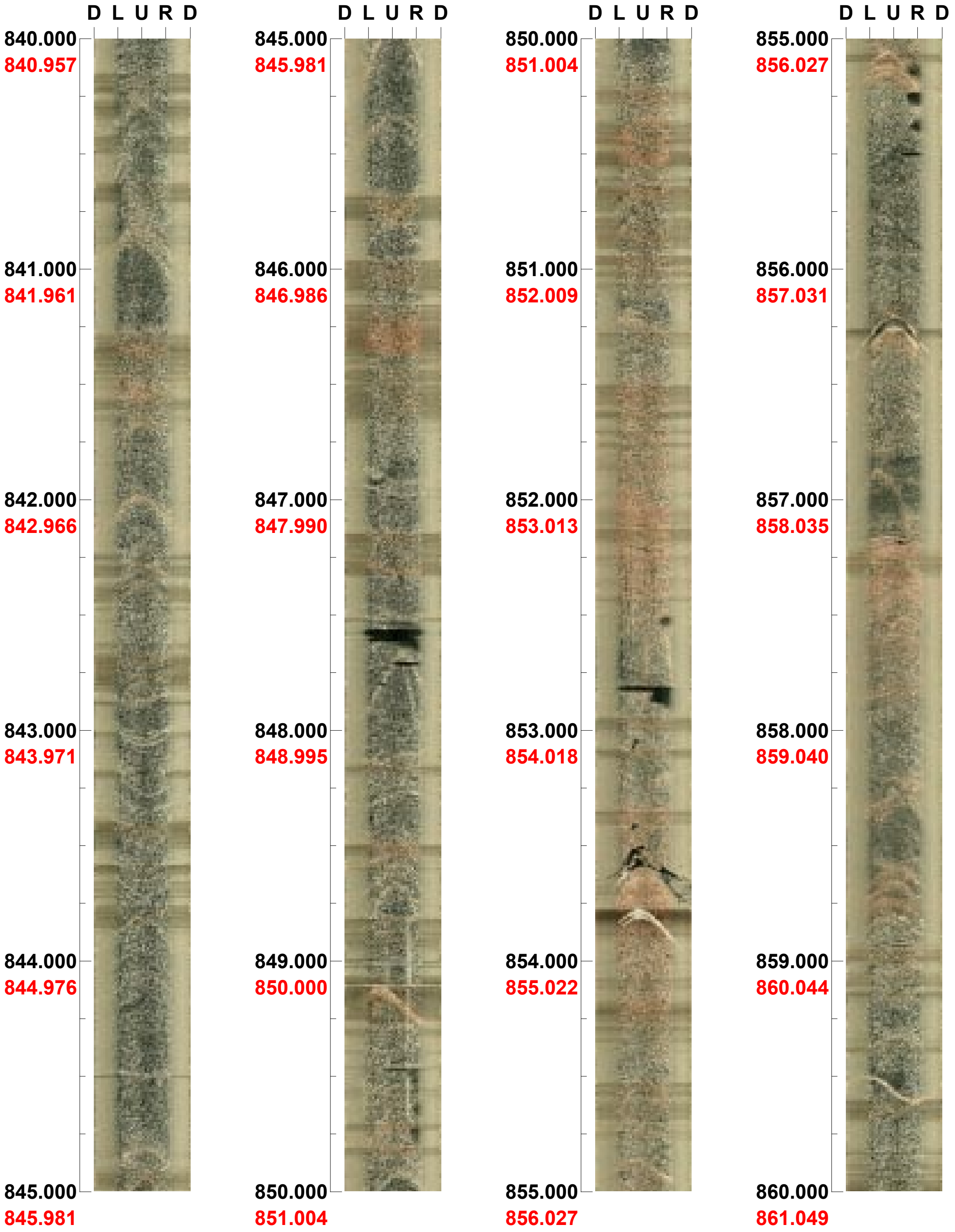
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 820.000 - 840.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 840.000 - 860.000 m

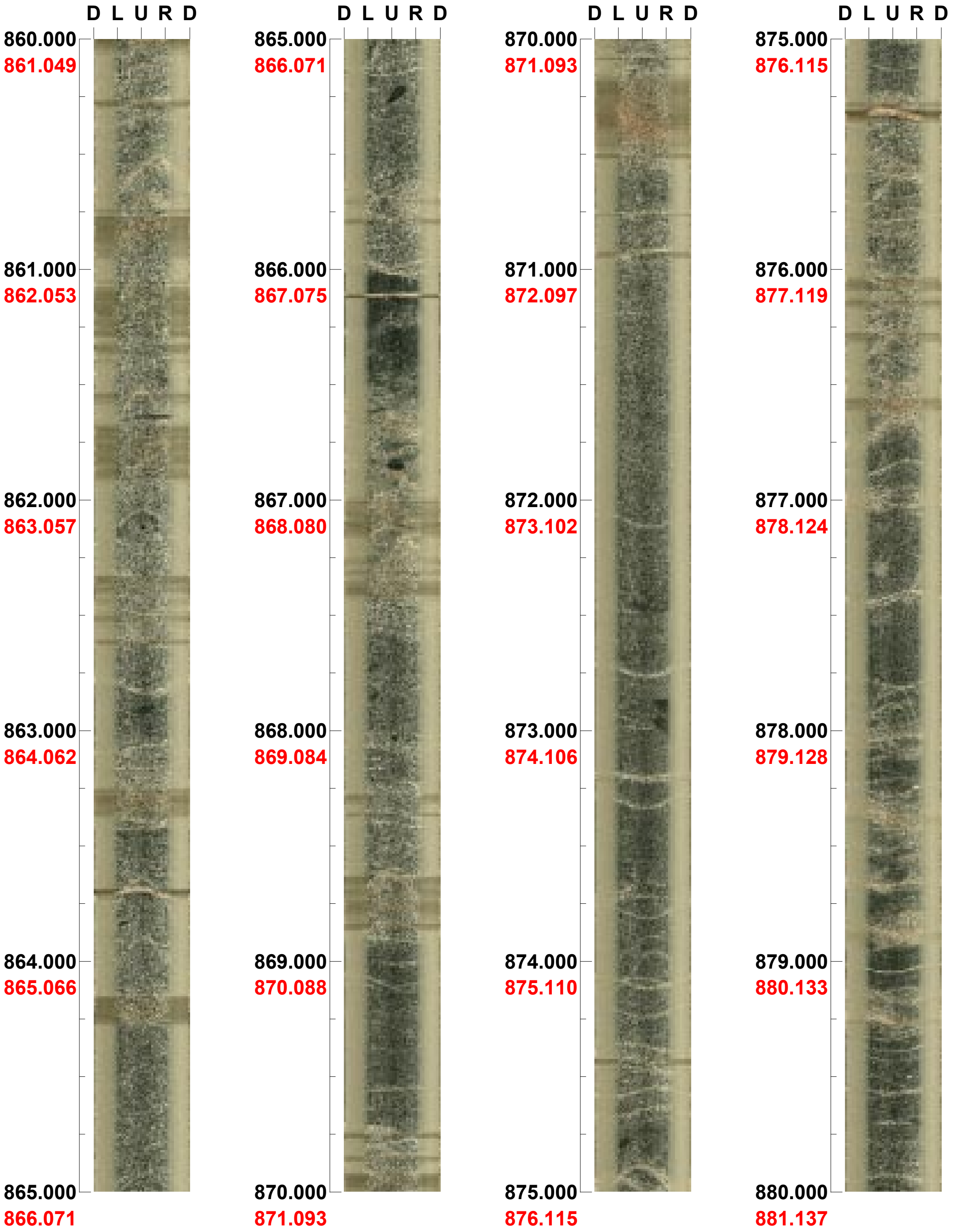


(14 / 21) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Laxemar

Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 860.000 - 880.000 m



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

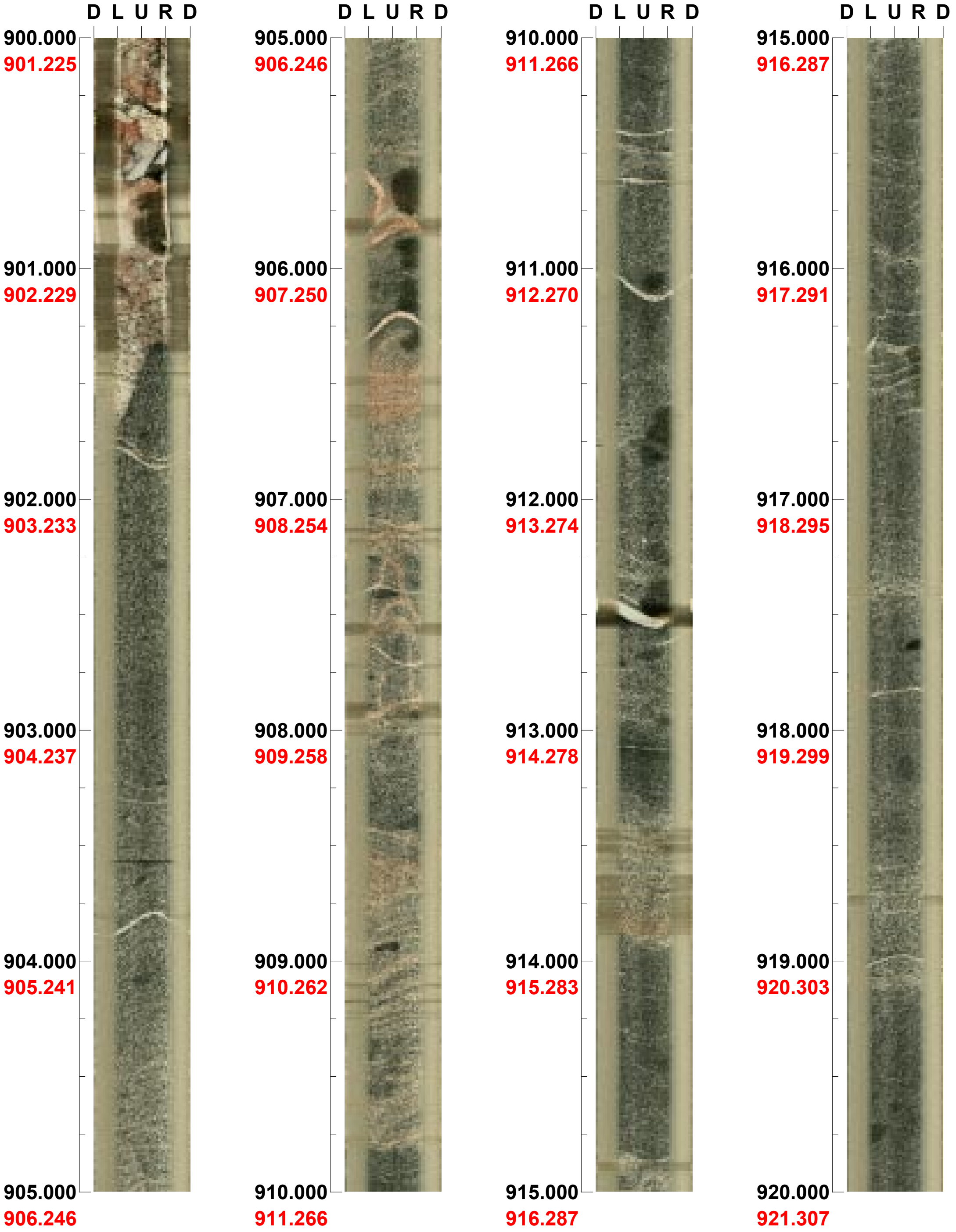
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 880.000 - 900.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

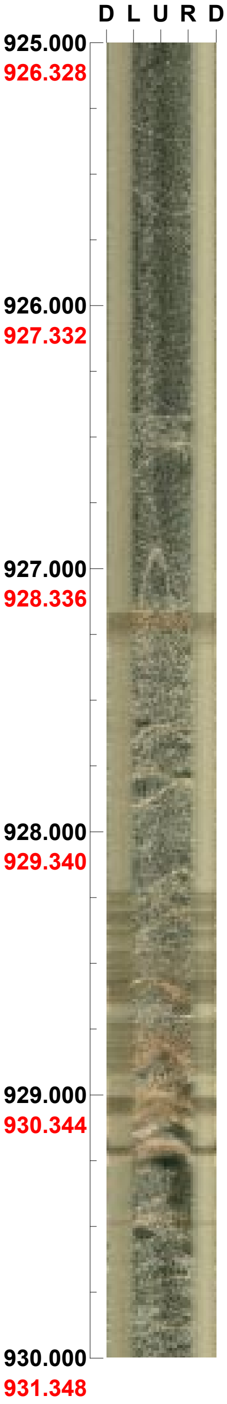
Depth range: 900.000 - 920.000 m

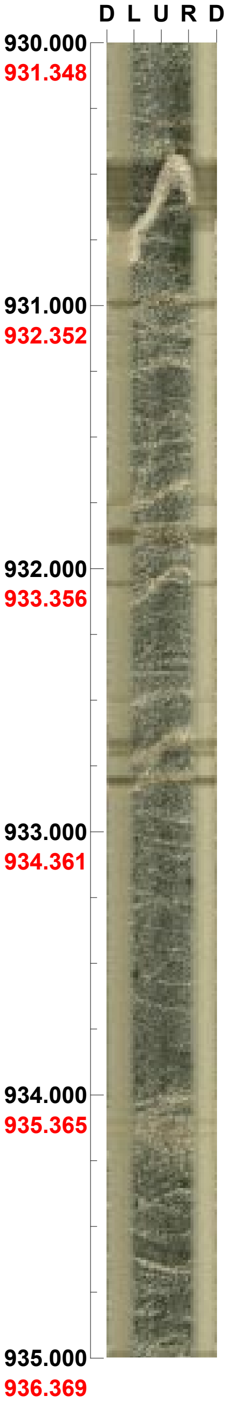


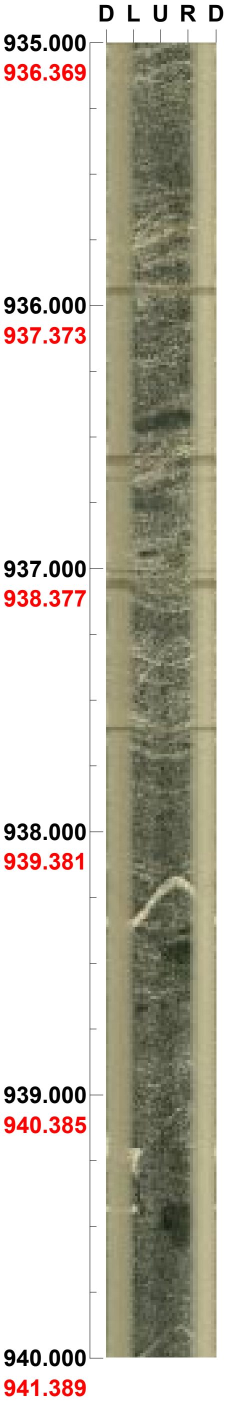
(17 / 21) **Scale: 1/25** **Aspect ratio: 175 %**

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 920.000 - 940.000 m







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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 940.000 - 960.000 m

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

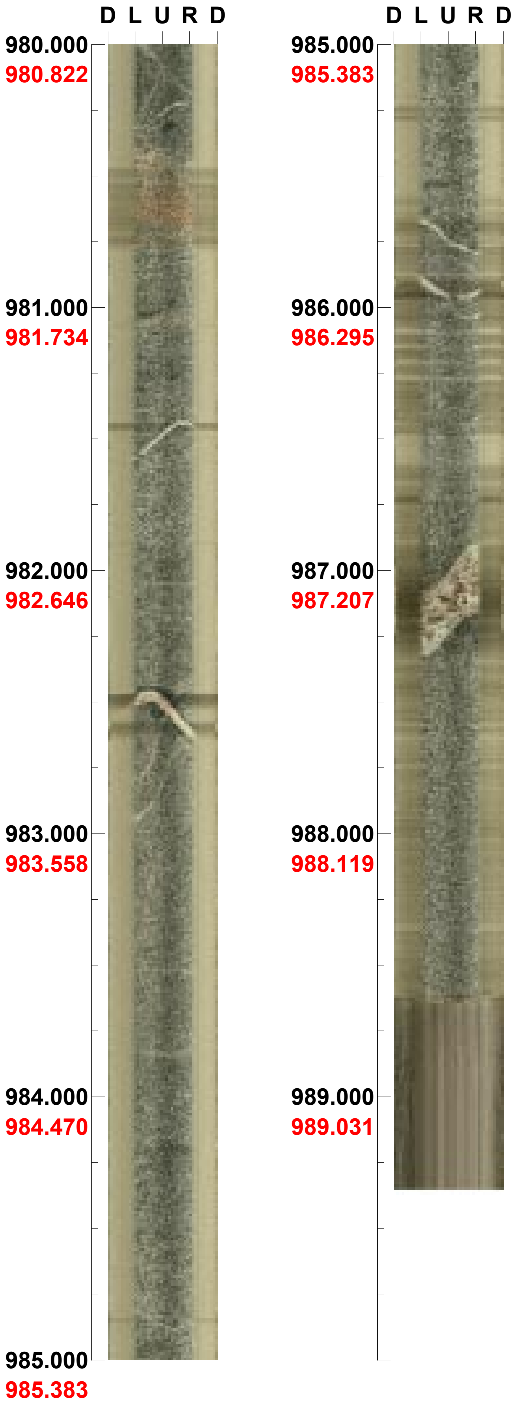
Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 960.000 - 980.000 m

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

Project name: Laxemar
Bore hole No.: KLX11A **Azimuth: 90** **Inclination: -76**

Depth range: 980.000 - 989.350 m



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