P-04-297

Oskarshamn site investigation

RAMAC and BIPS logging in boreholes HLX10, HLX26, HLX27 and HLX28

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November 2004

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ISSN 1651-4416
SKB P-04-297

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Keywords: BIPS, RAMAC, Radar, TV.

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.

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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 percussion-drilled boreholes HLX10, HLX26, HLX27 and HLX28. Originally borehole HLX11 and HLX12 was also planned to be logged. Unfortunately HLX11 was never found and HLX12 was blocked at 17 m during the dummy logging. All measurements were conducted by Malå Geoscience AB/RAYCON during October 2004.

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 HLX10, HLX26, HLX27 and HLX28 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. 18 reflectors were identified in HLX10 and the corresponding numbers for HLX26, HLX27 and HLX28 are 39, 37 and 35.

The BIPS images shows good possibilities for geological mapping and orientation of structures, due to high visibility of the borehole walls.

Sammanfattning

Denna rapport omfattar geofysiska loggningar inom platsundersökningsprogrammet för Oskarshamn. Mätningarna som presenteras här omfattar borrhålsradarmätningar (RAMAC) och BIPS-loggningar i borrhålen HLX10, HLX26, HLX27 och HLX28. Ursprungligen skulle även HLX11 och HLX12 ingå i undersökningen. Dock hittades aldrig HLX11 och i HLX12 fastande sonden under dummyloggningen redan på 17 m djup, och vidare mätningar genomfördes ej. Alla mätningar är utförda av Malå Geoscience AB /RAYCON under oktober 2004.

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 HLX10, HLX26, HLX27 och HLX28 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 från borrhålsradardata. Dock har 18 radarreflektorer identifierats i HLX10. Motsvarande antal för HLX26, HLX27 och HLX28 är 39, 37 och 35.

BIPS bilderna visar att förutsättningarna för geologisk kartering och sprickorientering är mycket goda tack vara god visibilitet av borrhålsväggen.

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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) and TV-logging (BIPS) in the percussion-drilled boreholes HLX10, HLX26, HLX27 and HLX28. The work was carried out in accordance with activity plan AP PS 400- 04-099. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents. All data has been inserted in the SICADA database and field note no is listed in Table 1-2.

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

Activity plan	Number	Version
Borrhålsradar och BIPS i HLX10, HLX11, HLX12 samt i HLX26, HLX27 och HLX28	AP PS 400-04-099	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för TV- loggning med BIPS	SKB MD 222.006	1.0
Metodbeskrivning för borrhålsradar	SKB MD 252.020	1.0

Table 1-2. Data references.

Subactivity	Database	Field note no
Bips o Radar loggning HLX10, 26, 27, 28	SICADA	FN 522

This report includes measurements from 0 to approximately 80 m in borehole HLX10. In HLX26 the loggings were performed to approximately 145 m depth, in HLX27 to approximately 155 m depth and to 140 m depth in HLX28. The boreholes are drilled with a diameter of approximately 140 mm.

All measurements were conducted by Malå Geoscience AB/RAYCON during October 2004. The 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 antennas.
- Borehole TV logging with the so-called BIPS system (Borehole Image Processing System), which is a high resolution, side viewing, colour borehole TV system.

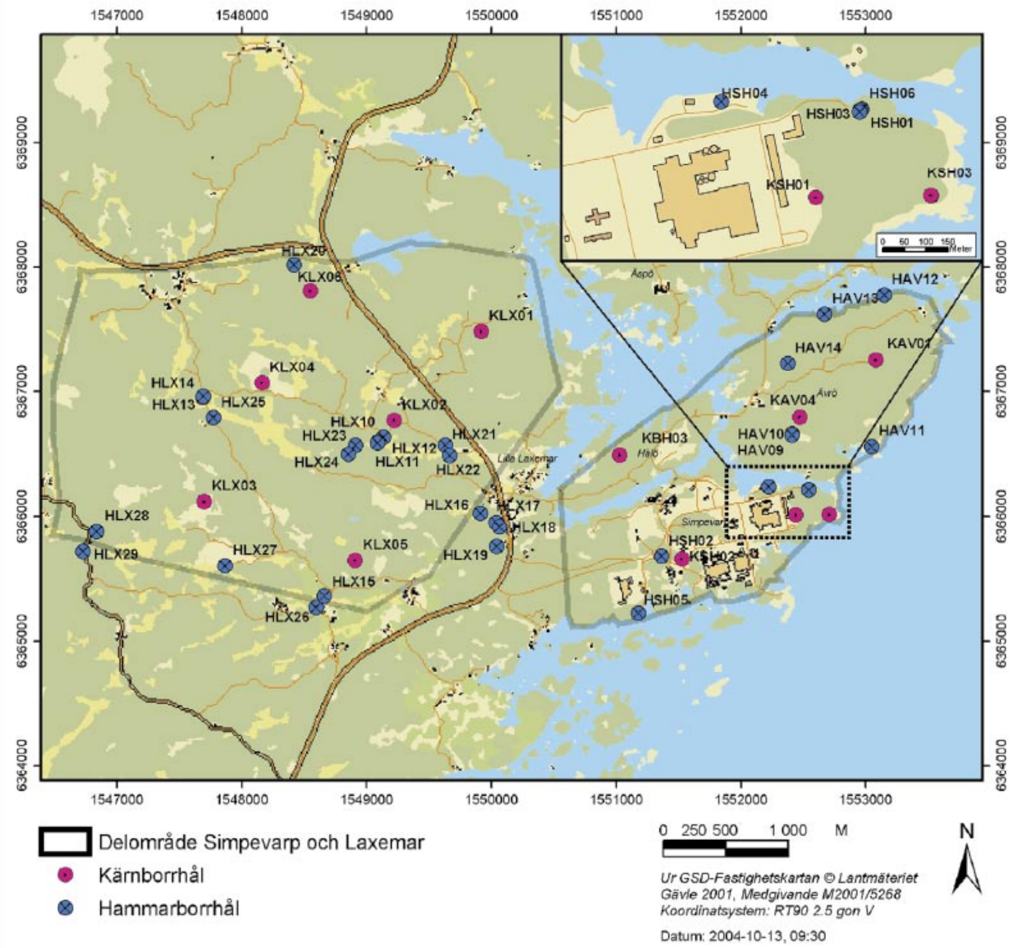


Figure 1-1. *General overview over the Simpevarp and Laxemar sub areas in Oskarshamn with the location of the boreholes HLX10, HLX26, HLX27 and HLX28.*

2 Objective and scope

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

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

3 Equipment

3.1 Radar measurements RAMAC

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

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

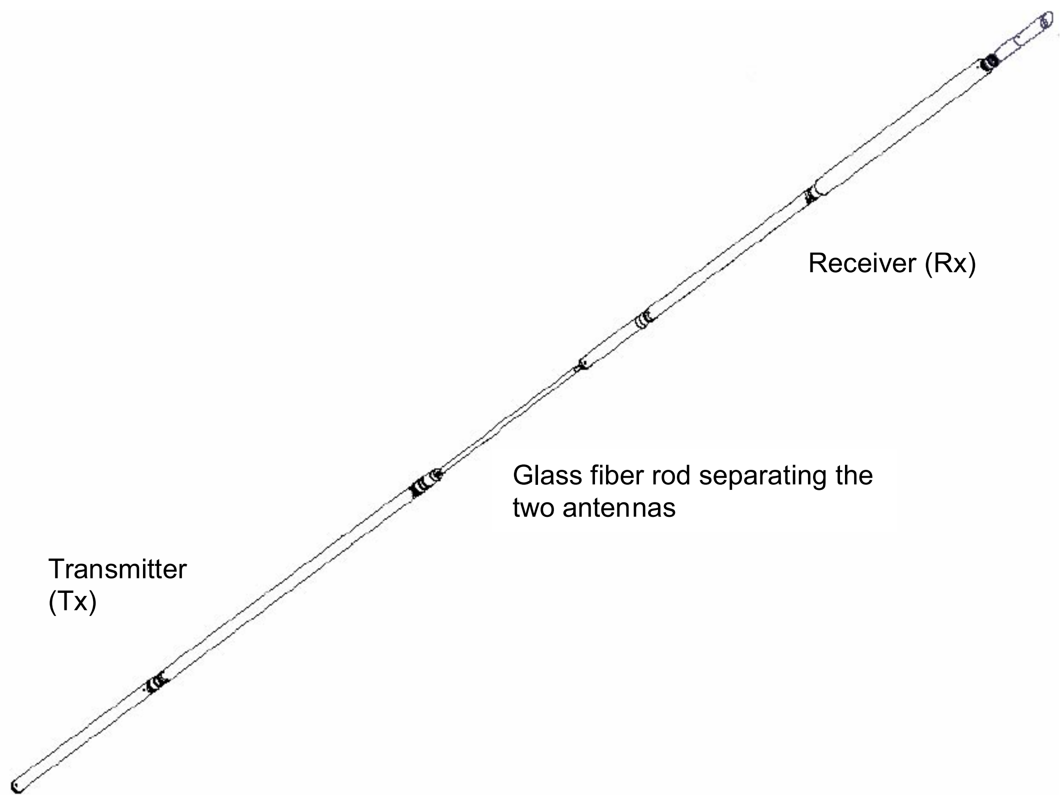


Figure 3-1. *Example of a borehole radar antenna.*

3.2 TV-Camera, BIPS

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

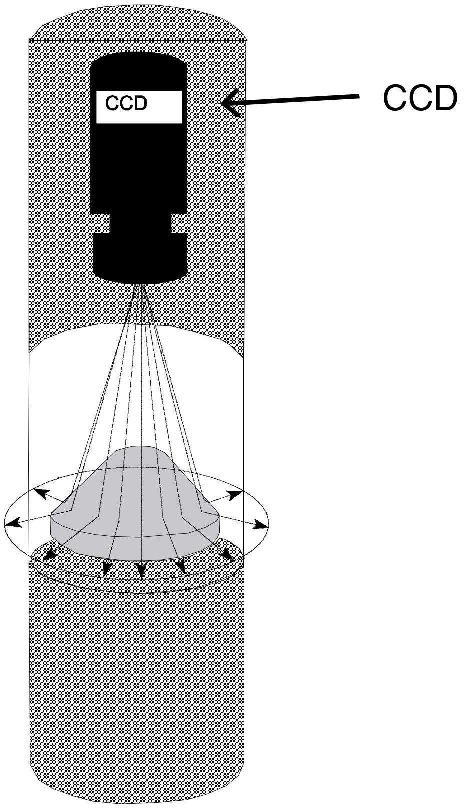


Figure 3-2. The BIP-system. Illustration of the conical mirror scanning.

4 Execution

4.1 General

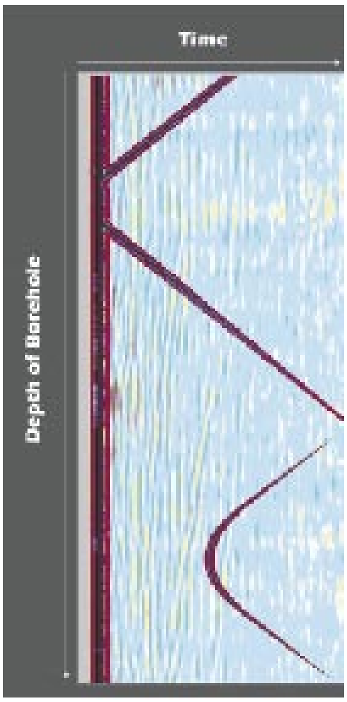
4.1.1 RAMAC Radar

The measurements in HLX10, HLX26, HLX27 and HLX28 were carried out with dipole radar antennas, with frequencies of 250, 100 and 20 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 antennas (transmitter and receiver) are kept at a fixed separation by glass fiber rods according to Table 4-1 to 4-4. See also Figure 3-1 and 4-1.

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

For more information on system settings used in the investigation of HLX10, HLX26, HLX27 and HLX28, see Table 4-1 to 4-4 below.



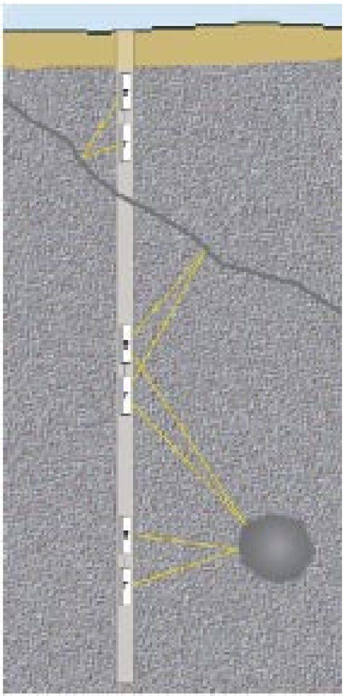


Figure 4-1. *The principle of radar borehole reflection survey and an example of result.*

Table 4-1. Radar logging information from HLX10.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**	
BH:	**HLX10**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Operator:	**CG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
Logging date:		04-10-20	04-10-20	04-10-20
Reference:		T.O.C.	T.O.C.	T.O.C.
Sampling frequency (MHz):		2424	891	239
Number of samples:		619	518	518
Number of stacks:		Auto	Auto	Auto
Signal position:		–0.34	–0.35	–1.54
Logging from (m):		1.5	2.6	6.25
Logging to (m):		83.5	82.4	78.3
Trace interval (m):		0.1	0.2	0.25
Antenna separation (m):		2.4	3.9	10.05

Table 4-2. Radar logging information from HLX26.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**	
BH:	**HLX26**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Operator:	**CG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
Logging date:		04-10-18	04-10-18	04-10-18
Reference:		T.O.C.	T.O.C.	T.O.C.
Sampling frequency (MHz):		2424	891	239
Number of samples:		619	518	518
Number of stacks:		Auto	Auto	Auto
Signal position:		–0.34	–0.35	–1.54
Logging from (m):		1.5	2.6	6.25
Logging to (m):		149.6	148.8	144.35
Trace interval (m):		0.1	0.2	0.25
Antenna separation (m):		2.4	3.9	10.05

Table 4-3. Radar logging information from HLX27.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**	
BH:	**HLX27**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Operator:	**CG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
Logging date:		04-10-19	04-10-19	04-10-19
Reference:		T.O.C.	T.O.C.	T.O.C.
Sampling frequency (MHz):		2424	891	239
Number of samples:		619	518	518
Number of stacks:		Auto	Auto	Auto
Signal position:		–0.34	–0.35	–1.54
Logging from (m):		1.5	2.6	6.25
Logging to (m):		161.5	160.5	156.25
Trace interval (m):		0.1	0.2	0.25
Antenna separation (m):		2.4	3.9	10.05

Table 4-4. Radar logging information from HLX28.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**	
BH:	**HLX28**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Operator:	**CG**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
Logging date:		04-10-20	04-10-20	04-10-20
Reference:		T.O.C.	T.O.C.	T.O.C.
Sampling frequency (MHz):		2424	891	239
Number of samples:		619	518	518
Number of stacks:		Auto	Auto	Auto
Signal position:		–0.34	–0.35	–1.54
Logging from (m):		1.5	2.6	6.25
Logging to (m):		142.1	141.6	136.25
Trace interval (m):		0.1	0.2	0.25
Antenna separation (m):		2.4	3.9	10.05

4.1.2 BIPS

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

During the measurement, a 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 boreholes HLX10, HLX26, HLX27 and HLX28.

In order to control the quality of the system, calibration measurements were performed in a test pipe before logging the first borehole (HLX26) and after logging the last one (HLX10), Figure 4-2. 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 5 to 8 in this report.

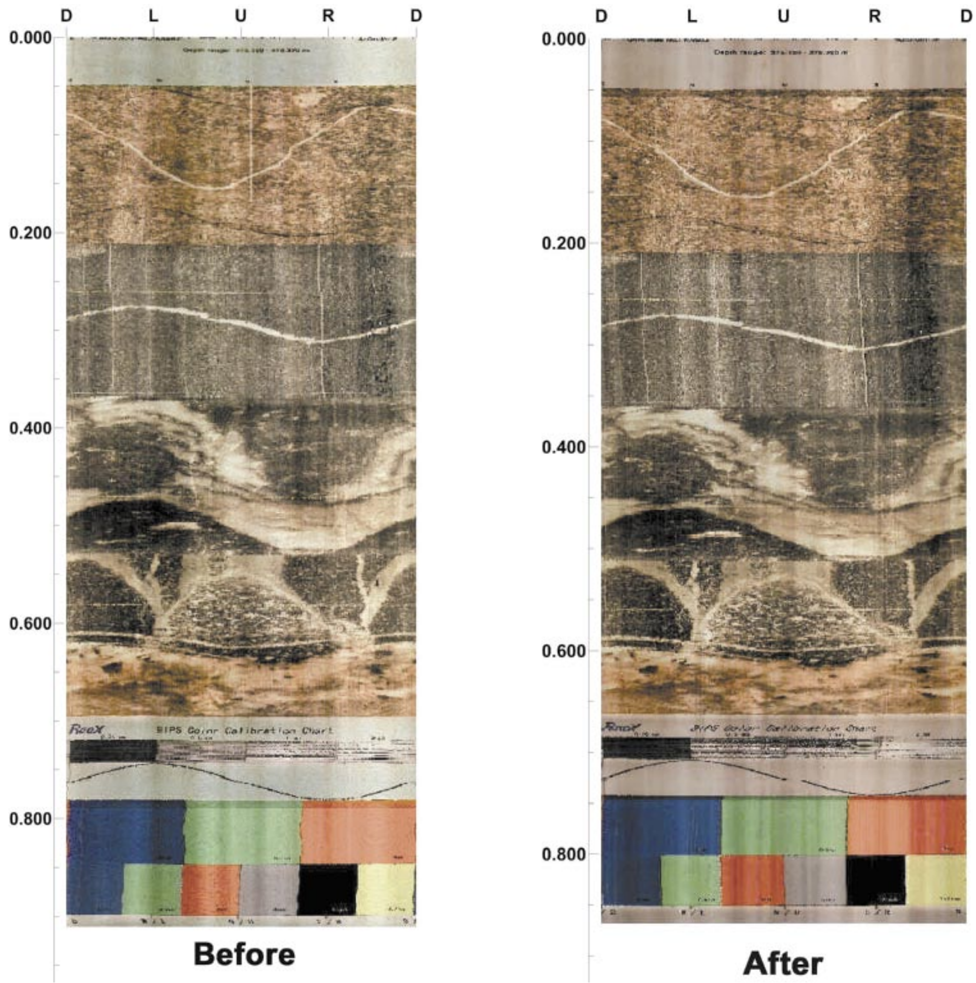


Figure 4-2. *Results from logging in the test pipe before and after the logging campaign in October.*

4.1.3 Length measurements

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

During the BIPS logging in core-drilled boreholes, were the reference marks in the borehole wall is visible on the image, the logging cable is marked with scotch tape. These tape marks are then used for controlling the RAMAC and BIPS measurements in percussion-drilled boreholes. The depth marks (presented in the Appendix 4 to 6) in the BIPS images represent the recorded depth (in black) and adjusted depth (in red).

The experience we have from earlier measurements with dipole antennas in the core-drilled boreholes in Forsmark and Oskarshamn for the radar logging is that the depth divergence is less than 50 cm in the deepest parts of the boreholes.

As all the measured boreholes are less than 200 m, the depth divergence is very slight, in the deepest parts of the boreholes.

4.2 Analyses and Interpretation

4.2.1 Radar

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

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

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

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

There are several ways to determine the radar wave propagation velocity. Each of them has its advantages and its disadvantages. In this project the velocity determination was performed by keeping the transmitter fixed in the borehole while moving the receiver downwards in the borehole. The result is plotted in Figure 4-3 and the calculation shows a velocity of 120 m/micro seconds. The velocity measurement was performed in borehole KSH01B with the 100 MHz antennas /1/.

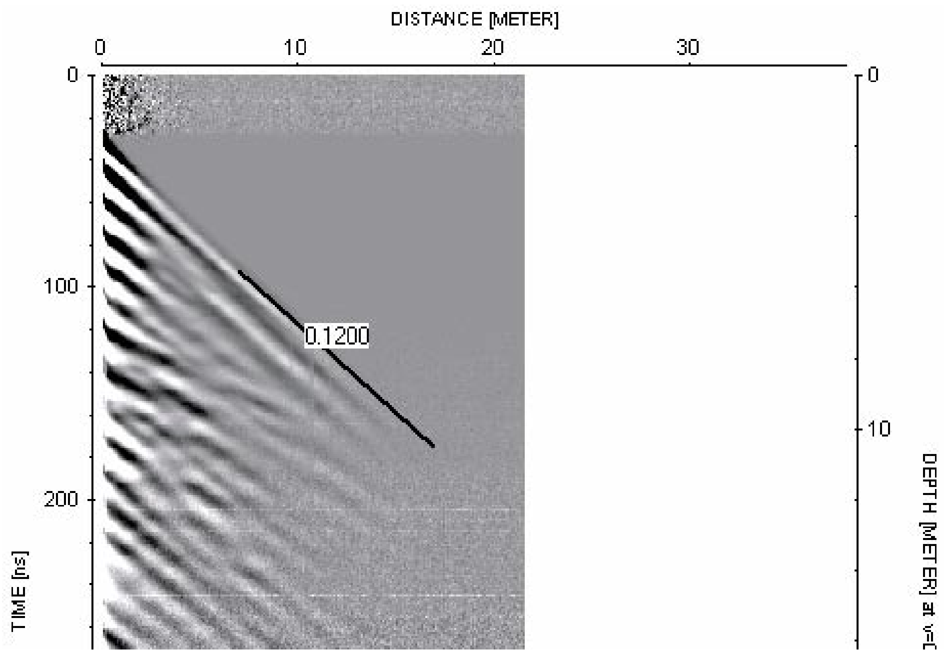


Figure 4-3. *Results from velocity measurements in KSH01B with 100 MHz dipole antennas /1/.*

The visualization of data in Appendix 1 to 4 is made with ReflexWin, a Windows based processing software for filtering and analysis of borehole radar data. The processing steps are shown in Tables 4-5 to 4-8. It should bee observed that the processing step below refer to the Appendix 1 to 4. 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 Tables 5-1 to 5-8 and are also visible on the radargrams in Appendix 1 to 4.

Table 4-5. Processing steps for borehole radar data from HLX10.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**	
BH:	**HLX10**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JA**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
Processing:		DC removal	DC removal	DC removal
		Move start time	Move start time	Move start time
		Gain	Gain	Gain

Table 4-6. Processing steps for borehole radar data from HLX26.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**	
BH:	**HLX26**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JA**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
Processing:		DC removal	DC removal	DC removal
		Move start time	Move start time	Move start time
		Gain	Gain	Gain

Table 4-7. Processing steps for borehole radar data from HLX27.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**	
BH:	**HLX27**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JA**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
Processing:		DC removal	DC removal	DC removal
		Move start time	Move start time	Move start time
		Gain	Gain	Gain

Table 4-8. Processing steps for borehole radar data from HLX28.

Site:	**Oskarshamn**	**Logging company:**	**RAYCON**	
BH:	**HLX28**	**Equipment:**	**SKB RAMAC**	
Type:	**Dipole**	**Manufacturer:**	**MALÅ GeoScience**	
Interpret:	**JA**	**Antenna**		
		250 MHz	**100 MHz**	**20 MHz**
Processing:		DC removal	DC removal	DC removal
		Move start time	Move start time	Move start time
		Gain	Gain	Gain

4.2.2 BIPS

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

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

4.3 Nonconformities

The BIPS logging in HLX10 stopped already at 27 m due to partly collapsed borehole. No problem to perform the radar logging to full depth. The borehole HLX11, an older investigation hole, was not found at the given location and was therefore not logged. During the dummy logging activity in HLX12 the dummy stopped in the borehole at a depth of approximately 17 m. Due to this no further logging was performed.

5 Results

The results from the BIPS measurements in HLX10, HLX26, HLX27 and HLX28 were delivered as raw data (*.bip-files) together with printable BIPS pictures in *.pdf format before the field crew left the investigation site. The information of the measurements was registered in SICADA, and the CD-ROM:s stored by SKB.

The RAMAC radar data for HLX10, HLX26, HLX27 and HLX28 was delivered as raw data (file format *.rd3 or *.rd5) with corresponding information files (file format *.rad) on CD-ROM:s to SKB before the field crew left the investigation site, whereas the data processing steps and results are presented in this report. Relevant information, including the interpretation presented in this report, was inserted into the SKB database SICADA.

The SICADA reference to the present activity is field note no 522.

5.1 RAMAC logging

The results of the interpretation of the radar measurements are presented in Tables 5-1 to 5-8. Radar data is also visualized in Appendix 1 to 4. It should be remembered that the images in Appendix 1 to 4 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 or other also exist, indicated in Appendix 1 to 4. See for instance HLX27, 20 MHz data. A very significant parallel structure is also seen in HLX28, 20 MHz data. These types of parallel structures do not get an intersection depth in RadInter, but should be noticed.

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.

The data quality from HLX10, HLX26, HLX27 and HLX28, (as seen in Appendix 1 to 4) 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 very clearly in the data from HLX26 between 60 and 70 m depth and in the lowermost part of HLX27. This conductive environment of course also reduces the possibility to distinguish and interpret possibly structures in the rock which otherwise could give a reflection.

Further on, depending on the size of the borehole, the conductivity and the antenna frequency, so called ringing can be achieved, which again makes the interpretation of single structures quite complicated. This is seen for instance on data from HLX28 (See Figure 5-1) and also for 250 MHz in HLX10 and HLX27 (see Appendix 1 and 3). Here a number of structures can be seen but it is quite impossible to know which reflection belongs to which structure. A part of this ringing can be removed with filtering, during interpretation.

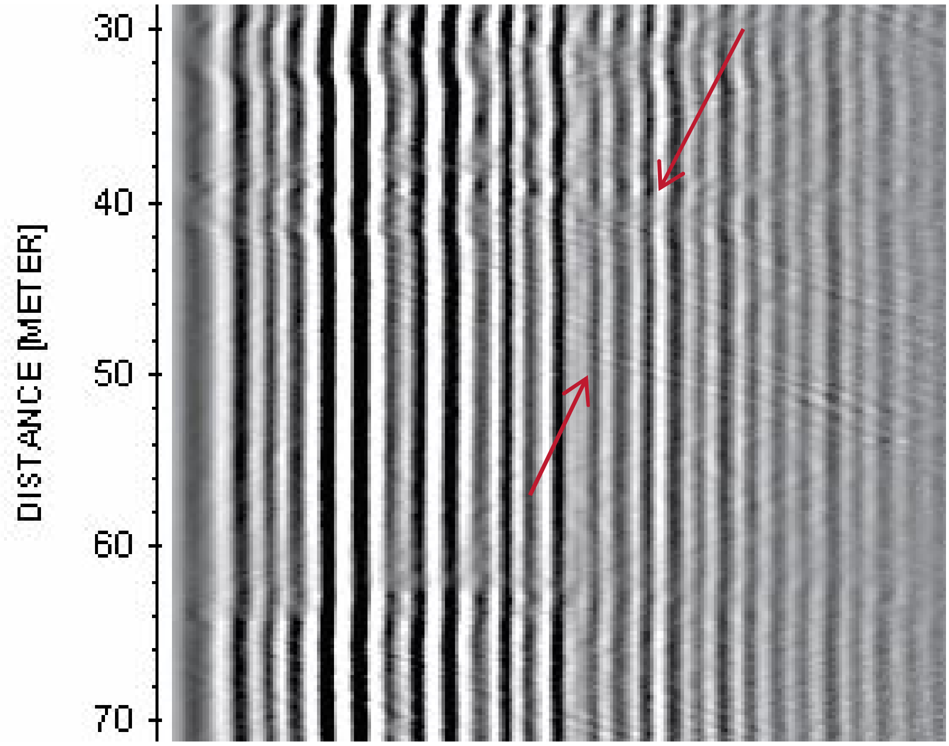


Figure 5-1. *Example of radargrams with an extensive so-called ringing (part of Appendix 4). A number of reflections are seen (between the black arrows) but it is hard to distinguish between those.*

As also seen in Appendix 1 to 4 the resolution and penetration of radar waves depend on the antenna frequency used. Low antenna frequency gives less resolution but higher penetration rate compared to a higher frequency. If structures can be identified with all three antenna frequencies, it can probably be explained by that the structure is quite significant.

In Tables 5-1 to 5-4 below the distribution of identified structures along the borehole are listed for HLX10, HLX26, HLX27 and HLX28.

Table 5-1. Identified structures as a function of depth in HLX10.

Depth (m)	No of structures
– 20	3
20–40	8
40–60	3
60–80	–
80–100	3
100–	1

Table 5-2. Identified structures as a function of depth in HLX26.

Depth (m)	No of structures
– 20	2
20–40	8
40–60	4
60–80	7
80–100	7
100–120	3
120–140	4
140–	4

Table 5-3. Identified structures as a function of depth in HLX27.

Depth (m)	No of structures
– 20	5
20–40	3
40–60	4
60–80	2
80–100	2
100–120	7
120–140	6
140–160	7
160–	2

Table 5-4. Identified structures as a function of depth in HLX28.

Depth (m)	No of structures
– 20	3
20–40	3
40–60	2
60–80	6
80–100	6
100–120	6
120–140	2
140–160	3
160–200	–
200–	4

Tables 5-5 to 5-8 summarises the interpretation of radar data from HLX10, HLX26, HLX27 and HLX28. In the tables the depth and intersection angle to the identified structures are listed.

Observe that a structure can have several different angles, if the structure is undulating, and thereby also different intersection depths. This is seen for structure Xo in Table 5-7. To this structure also structure X, Xx and Xxx belongs. The intersection depth is 159 m and the intersection angle varies between 13 and 53 degrees.

Table 5-5. Interpretation of radar reflectors from dipole antennas 20, 100 and 250 MHz borehole HLX10.

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas)			
Site:		**Oskarshamn**	
Borehole name:		**HLX10**	
Nominal velocity (m/μs):		**120.00**	
Object type	**Name**	**Intersection depth**	**Intersection angle**
PLANE	A	8.60	72
PLANE	N	15.70	55
PLANE	B	18.30	64
PLANE	C	20.40	41
PLANE	D	23.70	69
PLANE	E	25.40	64
PLANE	Fx	29.90	49
PLANE	F	30.00	68
PLANE	G	32.50	75
PLANE	H	36.20	60
PLANE	I	38.80	58
PLANE	J	43.20	62
PLANE	L	45.70	43
PLANE	K	47.60	55
PLANE	P	83.80	34
PLANE	M	86.20	43
PLANE	Q	93.00	52
PLANE	O	108.20	13

Table 5-6. Interpretation of radar reflectors from dipole antennas 20, 100 and 250 MHz in borehole HLX26.

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas)			
Site:		**Oskarshamn**	
Borehole name:		**HLX26**	
Nominal velocity (m/μs):		**120.00**	
Object type	**Name**	**Intersection depth**	**Intersection angle**
PLANE	I	10.00	28
PLANE	A	15.80	78
PLANE	B	20.40	64
PLANE	D	21.60	74
PLANE	C	24.20	54
PLANE	F	24.50	27
PLANE	E	30.50	39
PLANE	Ex	34.80	57
PLANE	G	37.30	76
PLANE	K	37.70	27
PLANE	H	40.50	33
PLANE	J	49.50	81
PLANE	L	49.10	26
PLANE	9	49.50	42
PLANE	M	61.50	67
PLANE	N	64.70	76
PLANE	8	66.10	36
PLANE	1	69.50	17
PLANE	O	71.30	71
PLANE	Px	78.70	65
PLANE	P	78.80	53
PLANE	R	82.20	64
PLANE	Q	84.20	64
PLANE	2	85.20	26
PLANE	S	86.30	69
PLANE	T	90.40	70
PLANE	U	95.20	79
PLANE	V	96.60	68
PLANE	W	101.40	75
PLANE	X	106.40	71
PLANE	Z	119.40	61
PLANE	Y	122.20	69
PLANE	Yx	122.20	76
PLANE	3x	137.10	74
PLANE	3	140.00	77
PLANE	5	147.60	76
PLANE	4	149.20	60
PLANE	6	157.10	55
PLANE	7	165.90	71

Table 5-7. Interpretation of radar reflectors from dipole antennas 20, 100 and 250 MHz in borehole HLX27.

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

Site: Oskarshamn
Borehole name: HLX27
Nominal velocity (m/μs): 120.00

Object type	Name	Intersection depth	Intersection angle
PLANE	B	10.10	44
PLANE	H	10.50	13
PLANE	A	10.40	66
PLANE	C	12.90	44
PLANE	E	19.60	37
PLANE	D	23.60	40
PLANE	Dx	24.60	44
PLANE	F	37.40	58
PLANE	G	40.50	59
PLANE	N	47.40	31
PLANE	I	48.10	56
PLANE	J	52.50	52
PLANE	K	60.50	60
PLANE	L	69.70	63
PLANE	M	82.50	64
PLANE	O	97.20	30
PLANE	4	101.40	68
PLANE	P	103.10	65
PLANE	5	103.80	77
PLANE	7	106.50	77
PLANE	8	108.90	74
PLANE	3	114.20	64
PLANE	6	114.50	49
PLANE	Q	125.40	48
PLANE	Xx	126.20	53
PLANE	R	128.10	68
PLANE	S	130.20	69
PLANE	2	135.30	65
PLANE	T	139.20	49
PLANE	U	142.40	48
PLANE	W	152.20	50
PLANE	V	155.30	47
PLANE	Y	152.70	35
PLANE	Xxx	153.40	33
PLANE	Z	156.90	67
PLANE	Xo	159.0	37
PLANE	1	165.10	33
PLANE	X	179.70	13

Table 5-8. Interpretation of radar reflectors from dipole antennas 20, 100 and 250 MHz in borehole HLX28.

RADINTER MODEL INFORMATION (20, 100 and 250 MHz Dipole Antennas)			
Site:		**Oskarshamn**	
Borehole name:		**HLX28**	
Nominal velocity (m/μs):		**120.00**	
Object type	**Name**	**Intersection depth**	**Intersection angle**
PLANE	5	–65.00	17
PLANE	A	10.60	56
PLANE	B	11.50	39
PLANE	F	22.40	52
PLANE	C	31.80	49
PLANE	H	39.90	51
PLANE	E	41.90	48
PLANE	G	44.30	54
PLANE	T	60.00	53
PLANE	1	60.80	45
PLANE	J	63.00	43
PLANE	I	63.90	51
PLANE	P	76.00	24
PLANE	K	76.50	53
PLANE	L	80.80	61
PLANE	2	85.10	48
PLANE	M	86.80	57
PLANE	4	90.00	52
PLANE	N	94.70	58
PLANE	O	97.70	57
PLANE	8	105.20	62
PLANE	R	108.70	48
PLANE	S	115.30	56
PLANE	W	116.20	39
PLANE	Wx	116.90	77
PLANE	U	117.80	20
PLANE	3	121.20	50
PLANE	Vx	138.30	38
PLANE	Z	141.10	82
PLANE	V	142.50	27
PLANE	Y	154.80	47
PLANE	Q	205.30	10
PLANE	X	251.40	5
PLANE	6	436.00	7
PLANE	7	520.00	6

In Appendix 1 to 4, 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 Tables 5-9 to 5-12.

Table 5-9. Decrease in amplitude for the 250 MHz antenna for borehole HLX10.

Depth (m)
15–20
25–35
35–50
75
80–

Table 5-10. Decrease in amplitude for the 250 MHz antenna for borehole HLX26.

Depth (m)
10–20
50
65–75

Table 5-11. Decrease in amplitude for the 250 MHz antenna for borehole HLX27.

Depth (m)
55
135–

Table 5-12. Decrease in amplitude for the 250 MHz antenna for borehole HLX28.

Depth (m)
15
75–85
105–110
115

5.2 BIPS logging

The BIPS pictures are presented in Appendix 5 to 9.

To get the best possible depth accuracy, the BIPS images are adjusted to the reference marks on the logging cable. In percussion drilled boreholes we use these marks on the cable as reference for the depth adjustment. The experience from one year of logging is that the marks on the logging cable is very good and differs very little compared with the results from core-drilled boreholes. At present we have marks at 110, 150 and 200 m on the logging cable that are used for depth adjustments of the BIPS results in percussion drilled boreholes.

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

Data for the inclination and azimuth presented in this report for the boreholes are only preliminary (reference from AP PS 400-04-099).

5.2.1 HLX10

The images from the borehole is of good quality down to 27 m were the probe stopped. The reason for the stop is probably due to the centralisers attached on the probe. The centralisers have an OD of 124 mm and at 27 m there is most probably some stones that squeezes in to the borehole and make it impossible to pass with such a big probe. There was no problem to enter in to this section with the radar probes (OD of 48 mm). It is important to use centralisers for the BIPS method, as a bad centralised probe give very divided condition for the light and also causes errors in the dip analyses.

5.2.2 HLX26

The images are perfect except for the last 5 m were mud covers the lower most part of the borehole wall.

5.2.3 HLX27

The visibility was not perfect throughout the borehole due to bad water quality. The visibility improves further down in the borehole. At 158.5 m adjusted depth (Figure 5-2) there is a big open fracture zone that intersects the borehole. From the BIPS images there is impossible to see the thickness of this structure because of muddy water in the bottom. Reflector Xo in the radar 250 MHz, 100 MHz and 20 MHz radargrams corresponds very well to the intersection depth of this structure.

5.2.4 HLX28

Very good water quality and no mud on the borehole wall give images of high quality.

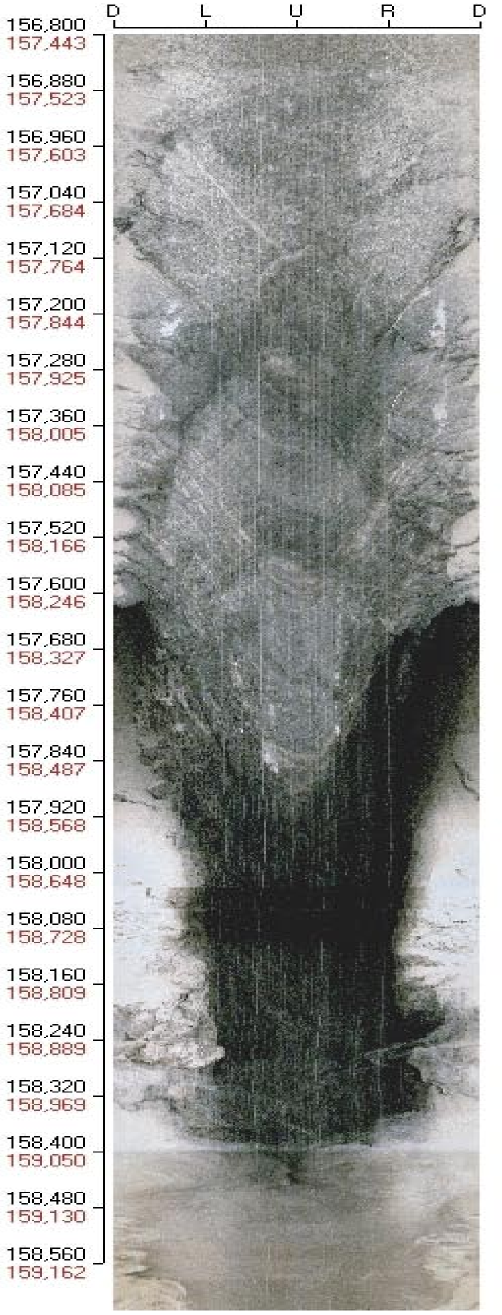


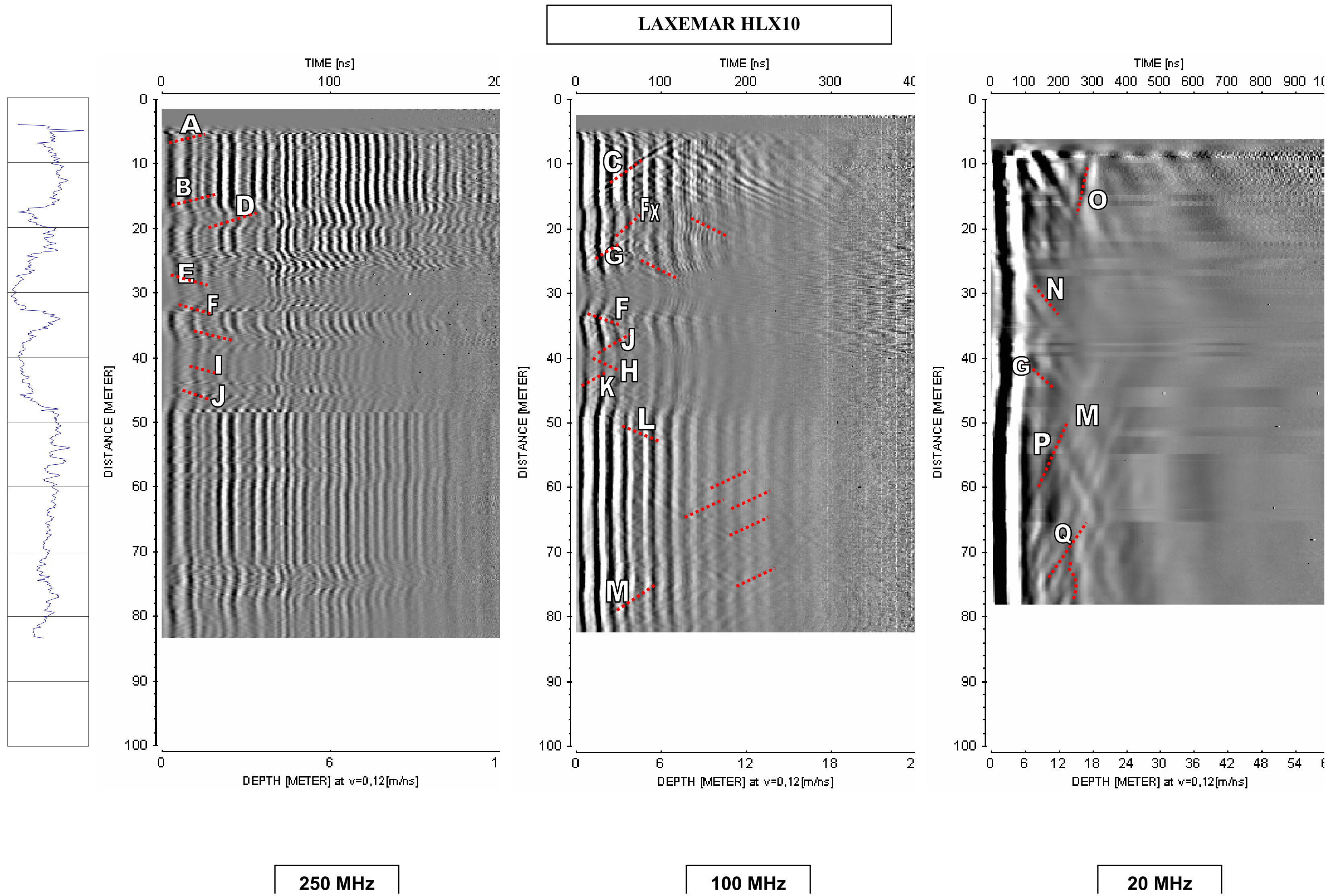
Figure 5-2. *BIPS image between 157.4 and 159.2 m in borehole HLX27.*

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

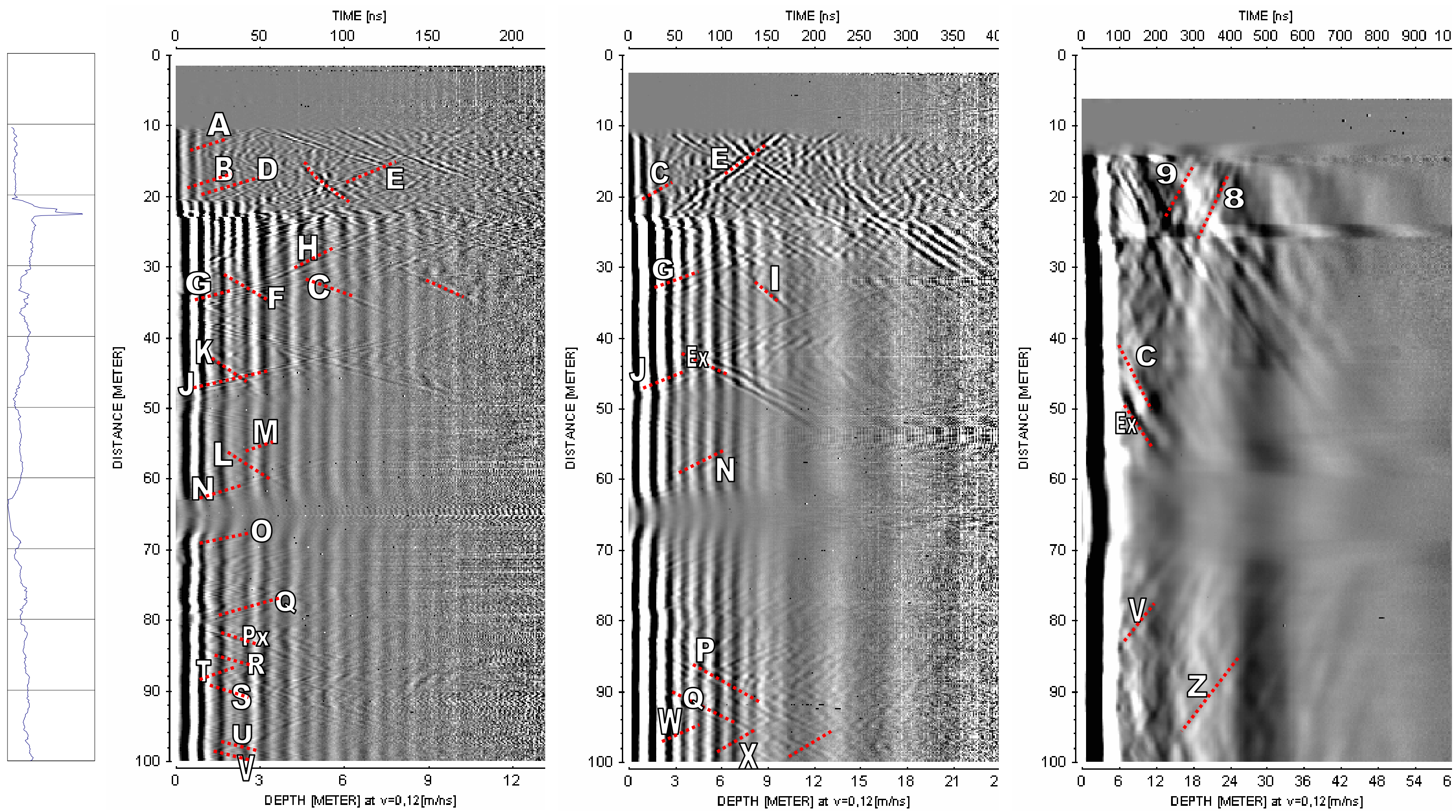
Radar logging in HLX10, 0 to 82 m, dipole antennas 250, 100 and 20 MHz



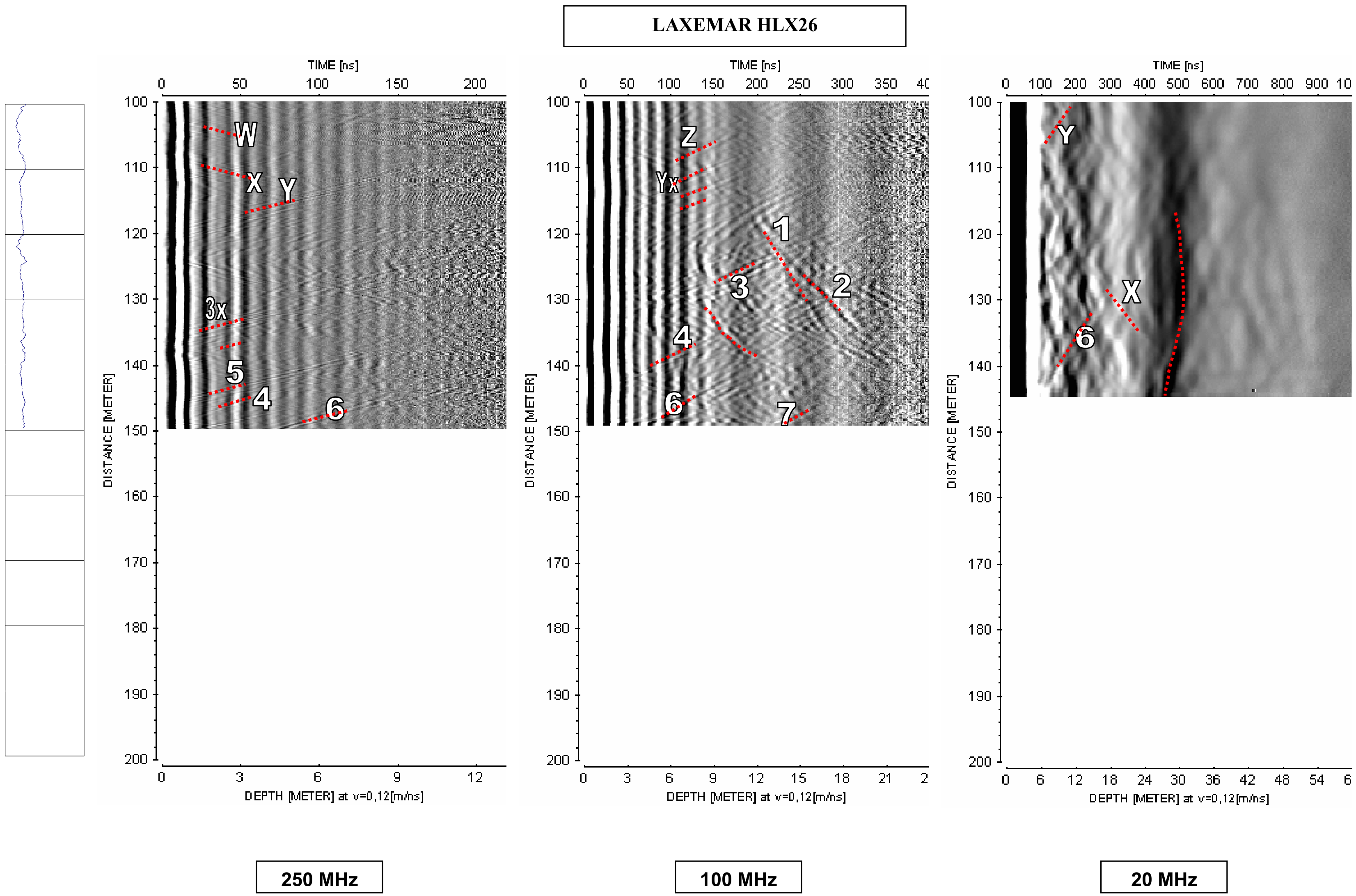
Appendix 2

Radar logging in HLX26, 0 to 148 m, dipole antennas 250, 100 and 20 MHz

LAXEMAR HLX26

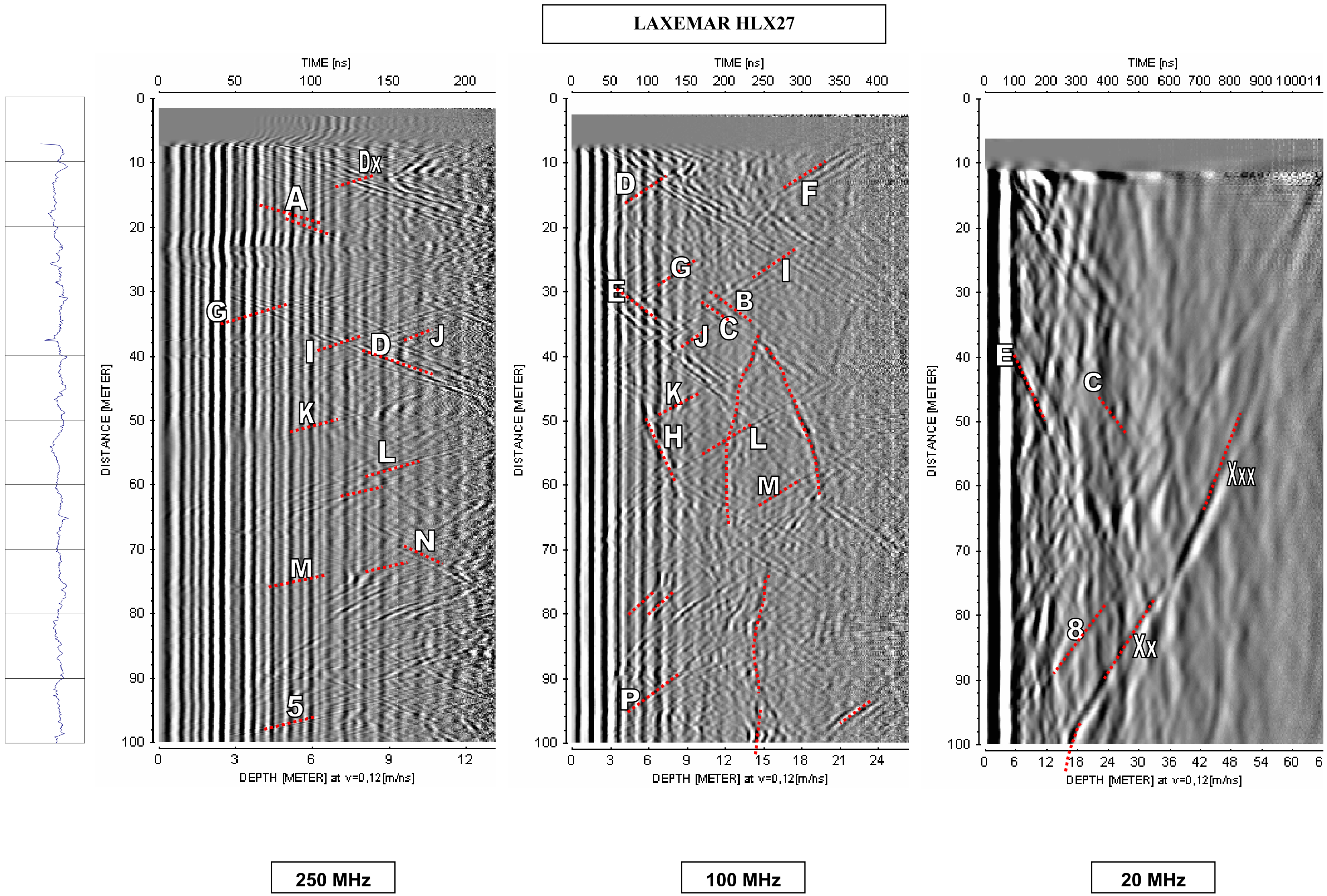


250 MHz **100 MHz** **20 MHz**

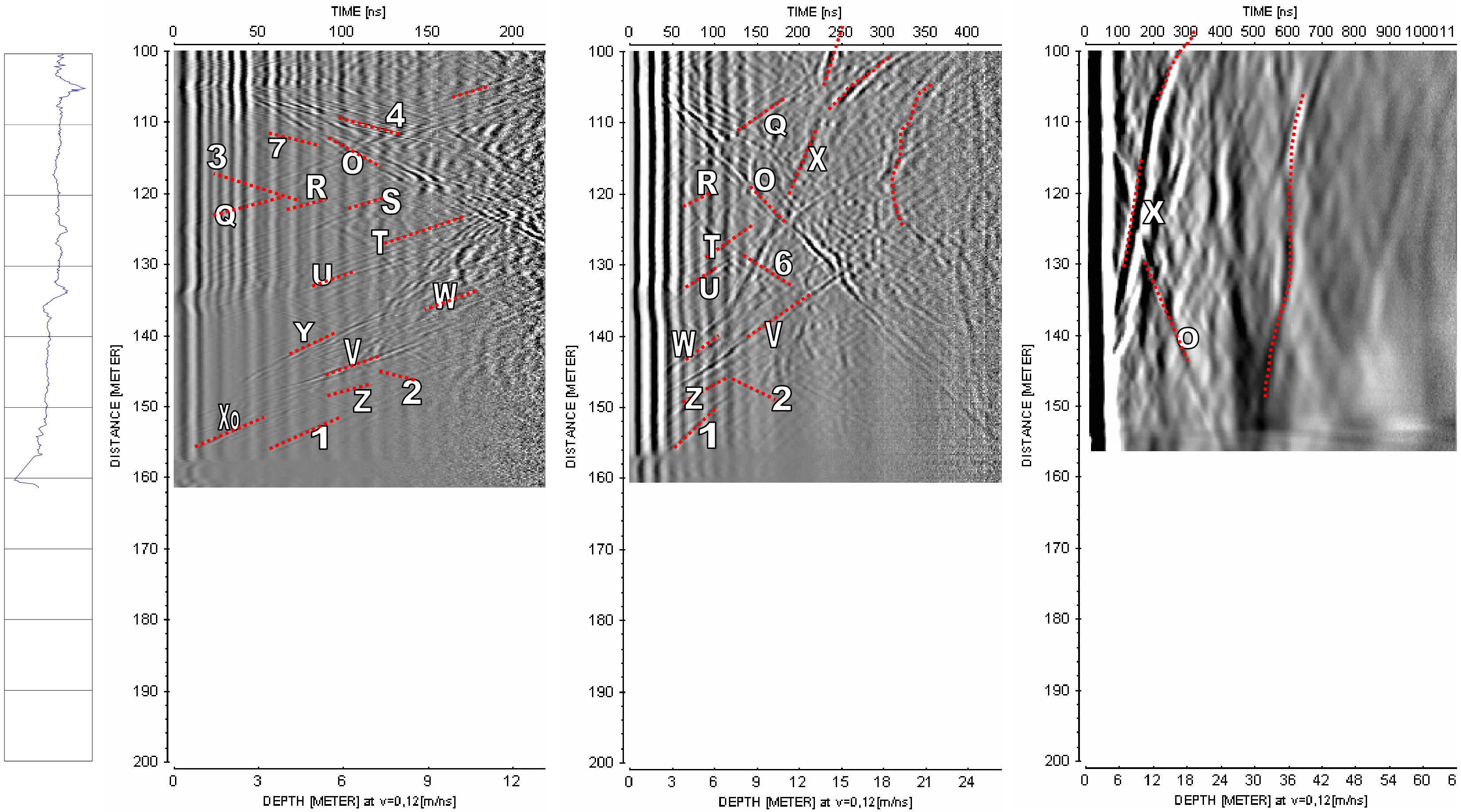

LAXEMAR HLX26
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,12[m/ns]
250 MHz
100 MHz
20 MHz
W
X
Y
Z
1
2
3
4
5
6
7

Appendix 3

Radar logging in HLX27, 0 to 159 m, dipole antennas 250, 100 and 20 MHz



LAXEMAR HLX27



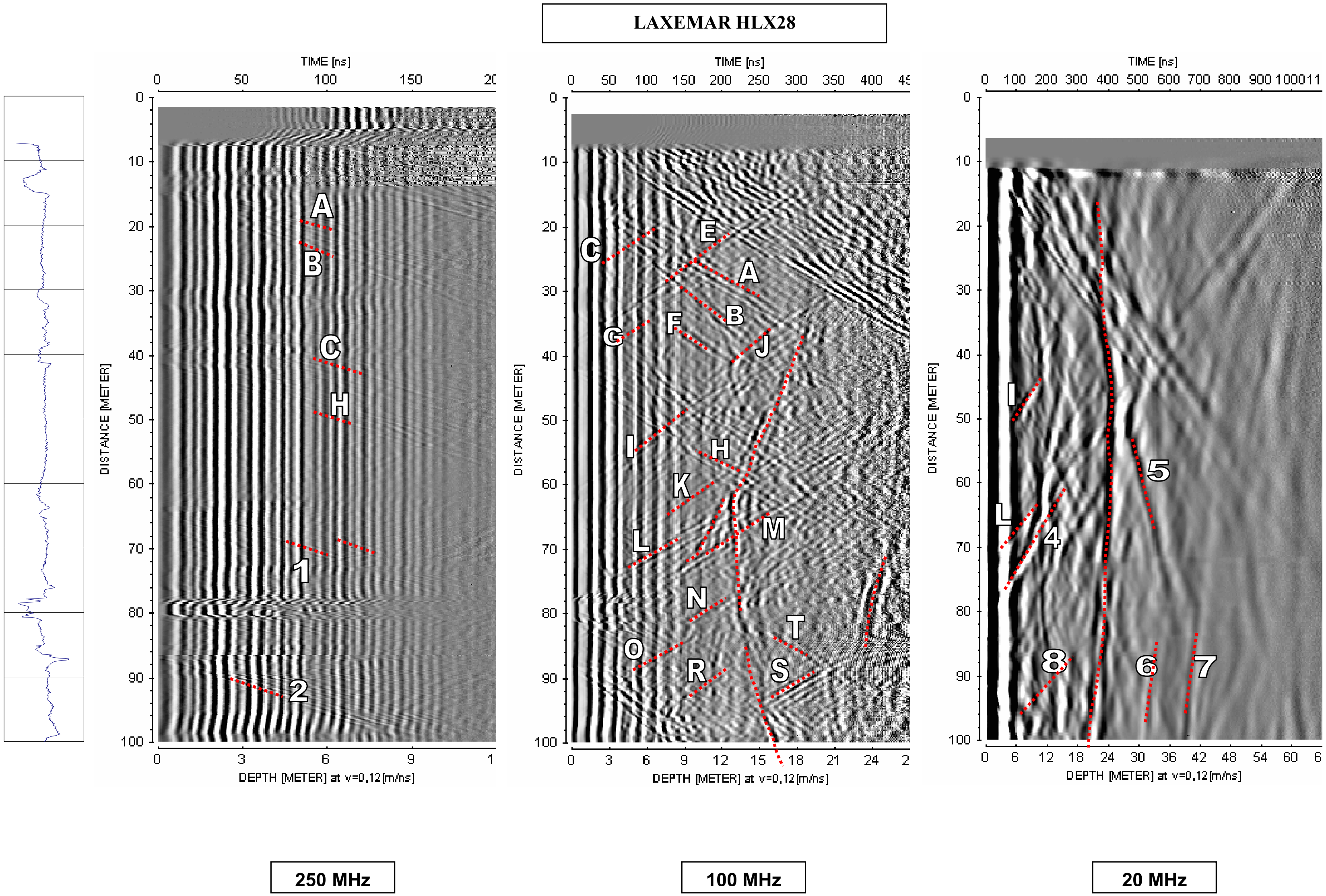
250 MHz

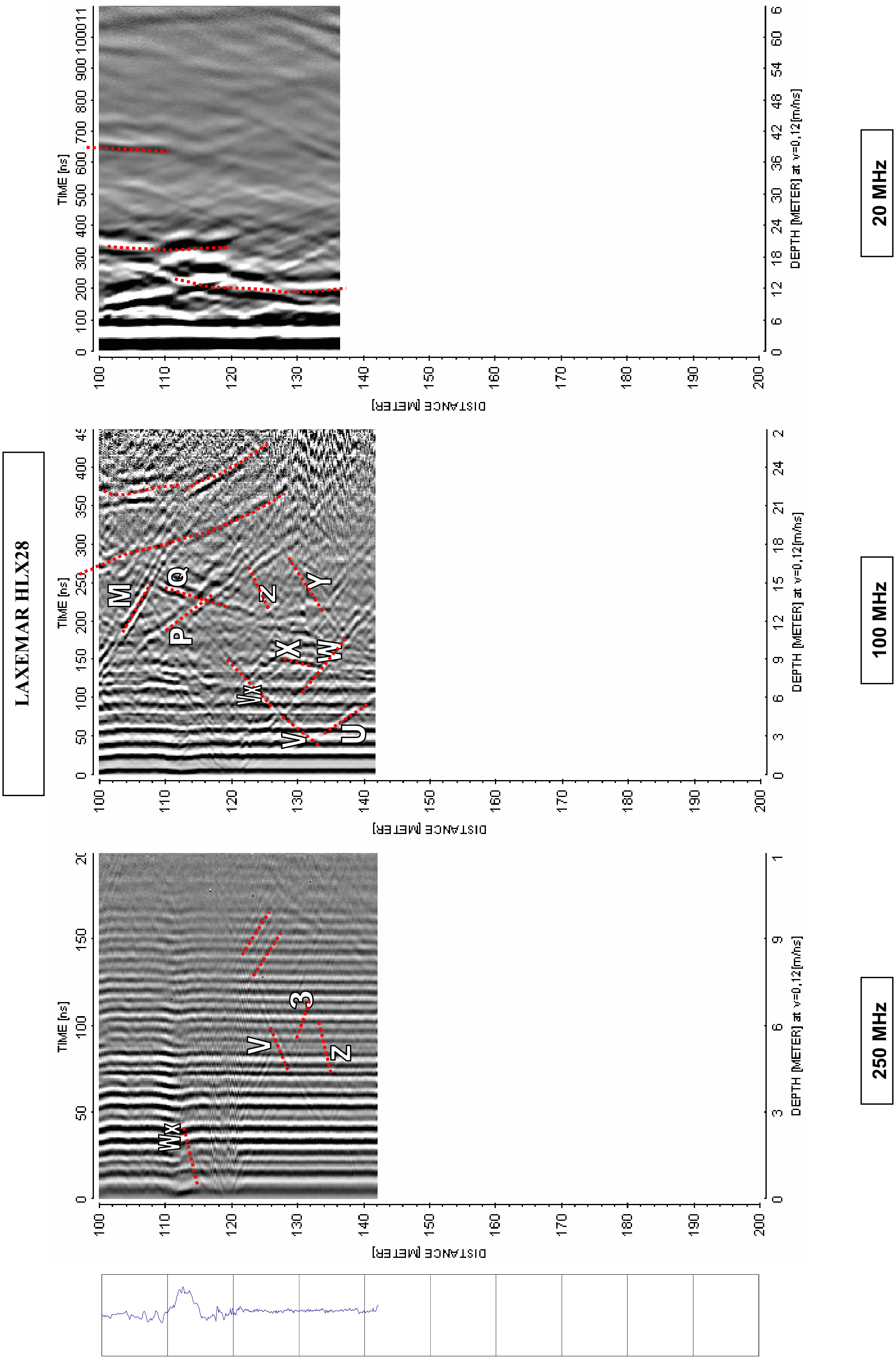
100 MHz

20 MHz

Appendix 4

Radar logging in HLX28, 0 to 140 m, dipole antennas 250, 100 and 20 MHz




LAXEMAR HLX28
20 MHz
100 MHz
250 MHz
TIME [ns]
DISTANCE [METER]
DEPTH [METER] at v=0,12[m/ns]
M
P
Q
Z
Y
X
W
Wx
V
U
3

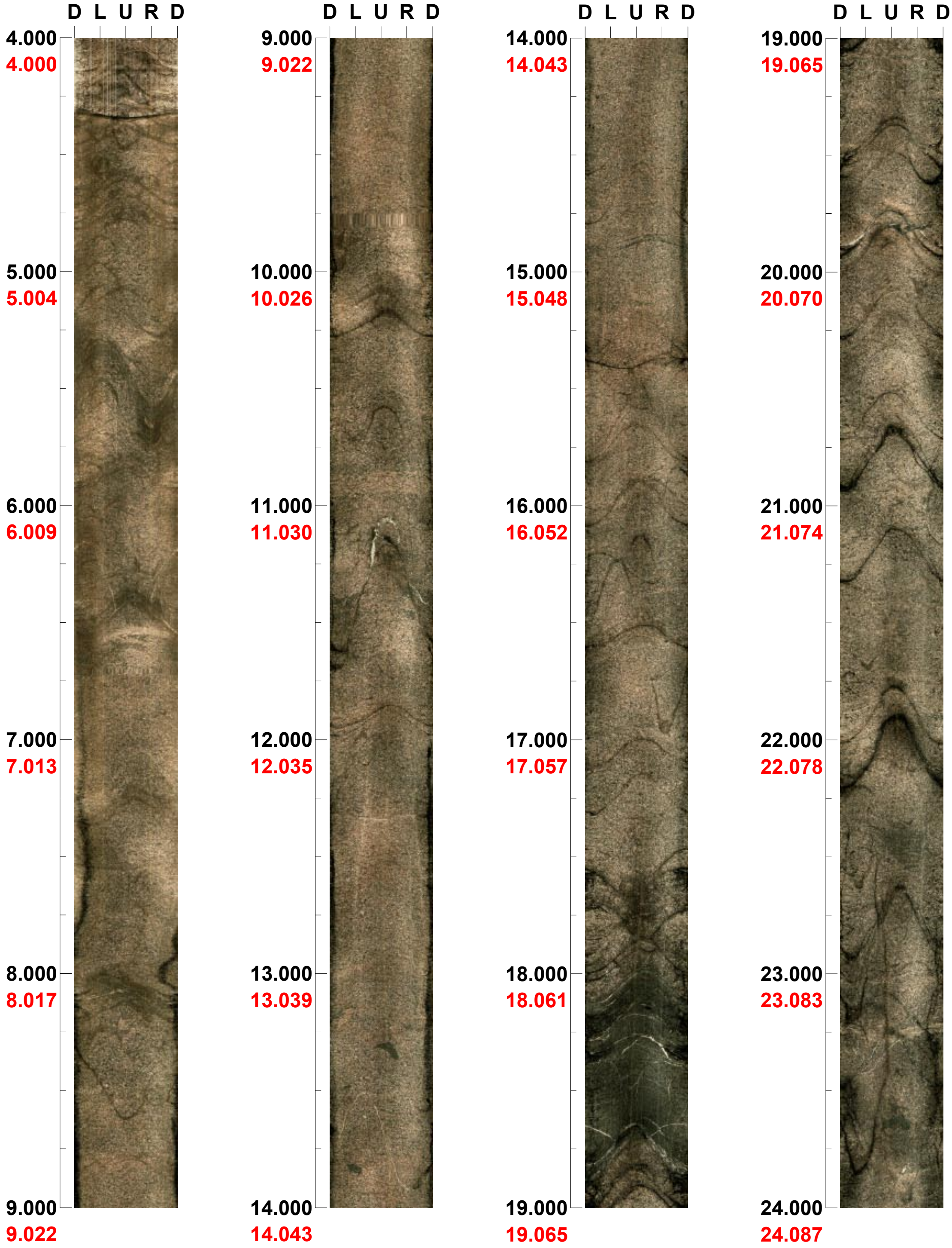
BIPS logging in HLX10, 4 to 27 m

Project name: Laxemar

Image file	: c:\work\r5347s~1\hlx10\bips\hlx10.bip
BDT file	: c:\work\r5347s~1\hlx10\bips\hlx10.bdt
Locality	: LAXEMAR
Bore hole number	: HLX10
Date	: 04/10/20
Time	: 16:29:00
Depth range	: 4.000 - 27.107 m
Azimuth	: 170
Inclination	: -70
Diameter	: 140.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 100 %
Pages	: 2
Color	: +0 +0 +0

Project name: Laxemar
Bore hole No.: HLX10 **Azimuth: 170** **Inclination: -70**

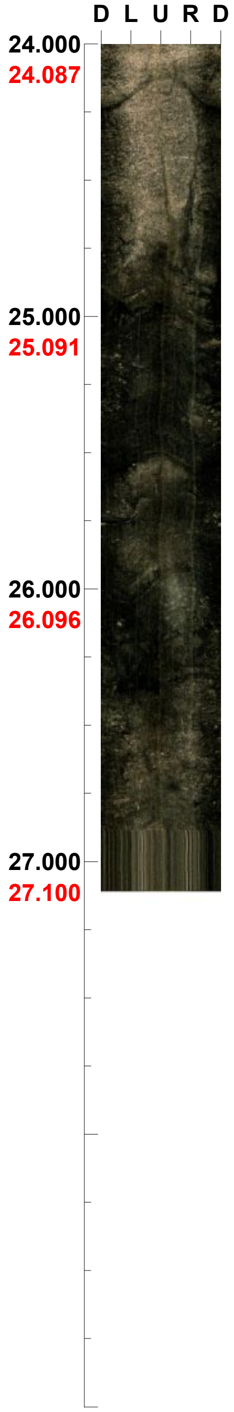
Depth range: 4.000 - 24.000 m



(1 / 2) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX10 **Azimuth: 170** **Inclination: -70**

Depth range: 24.000 - 27.107 m



(2 / 2) **Scale: 1/25** **Aspect ratio: 100 %**

Appendix 6

BIPS logging in HLX26, 9 to 151 m

Project name: Laxemar

Image file	: c:\work\r5347s~1\hlx26\bips\hlx26.bip
BDT file	: c:\work\r5347s~1\hlx26\bips\hlx26.bdt
Locality	: LAXEMAR
Bore hole number	: HLX26
Date	: 04/10/18
Time	: 14:26:00
Depth range	: 9.000 - 150.569 m
Azimuth	: 10
Inclination	: -60
Diameter	: 140.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 100 %
Pages	: 8
Color	: +0 +0 +0

Project name: Laxemar

Bore hole No.: HLX26 **Azimuth: 10** **Inclination: -60**

Depth range: 9.000 - 29.000 m

(1 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX26 **Azimuth: 10** **Inclination: -60**

Depth range: 29.000 - 49.000 m

(2 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

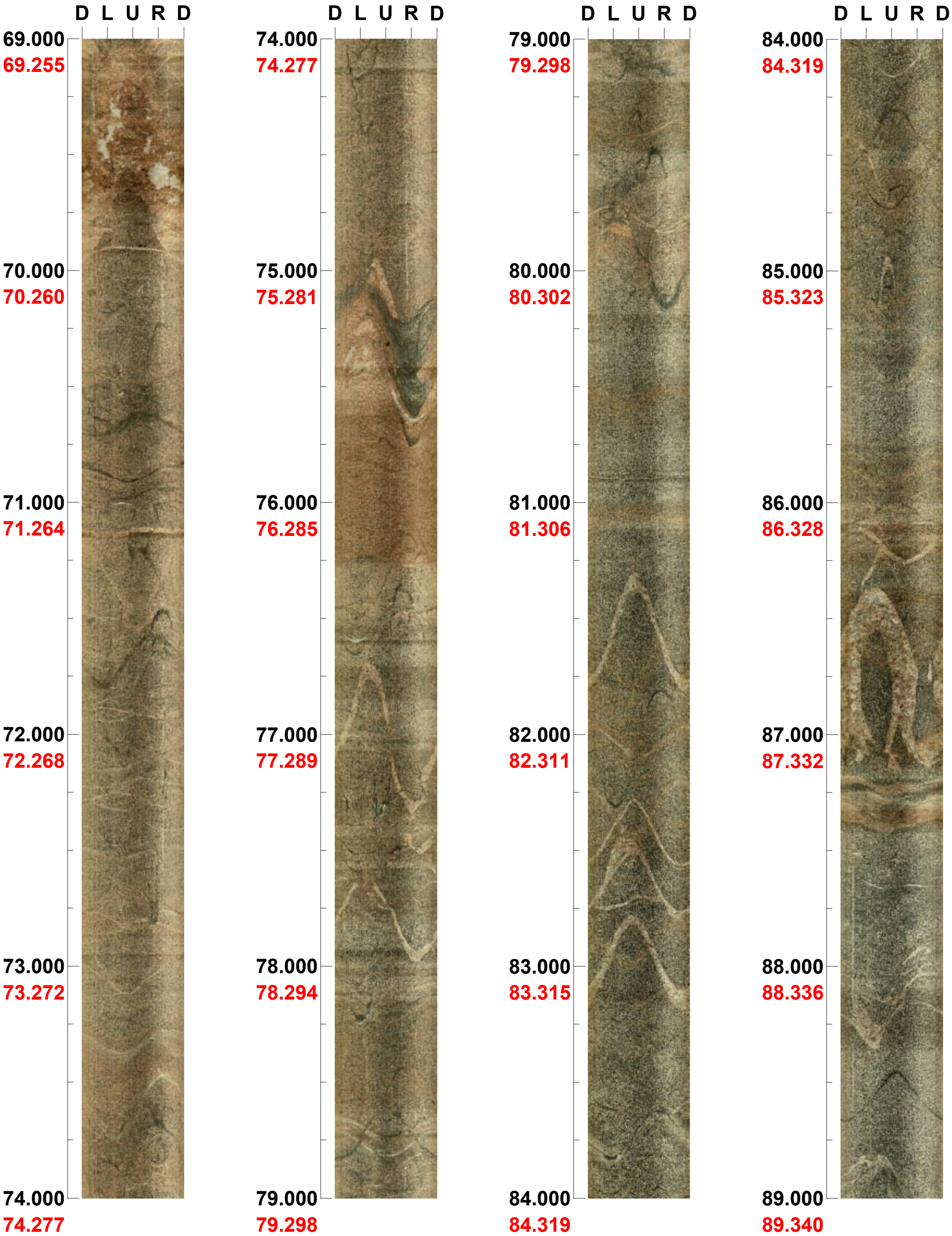
Project name: Laxemar
Bore hole No.: HLX26 **Azimuth: 10** **Inclination: -60**

Depth range: 49.000 - 69.000 m

(3 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX26 **Azimuth: 10** **Inclination: -60**

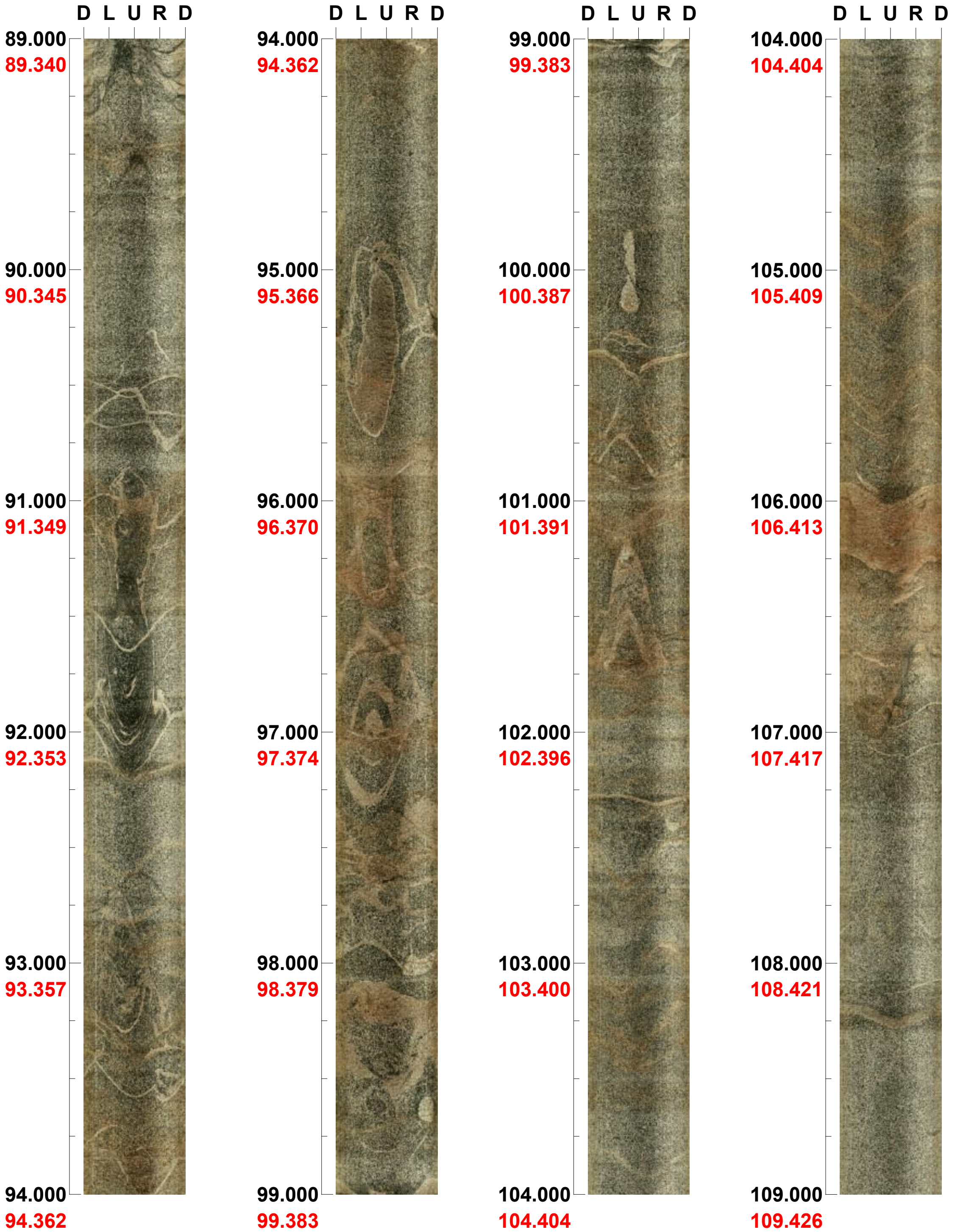
Depth range: 69.000 - 89.000 m



(4 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX26 **Azimuth: 10** **Inclination: -60**

Depth range: 89.000 - 109.000 m



(5 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX26 Azimuth: 10 Inclination: -60

Depth range: 109.000 - 129.000 m

D L U R D

109.000
109.426
110.000
110.430
111.000
111.434
112.000
112.438
113.000
113.443
114.000
114.447

D L U R D

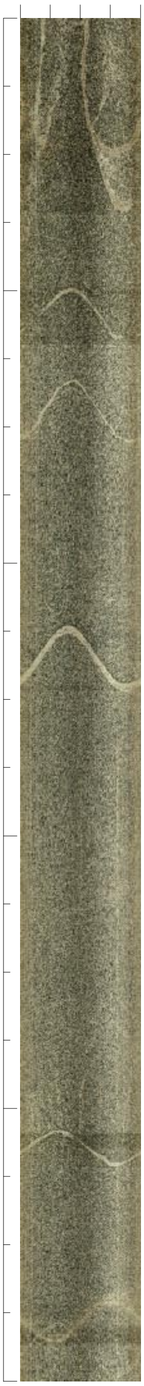
114.000
114.447
115.000
115.451
116.000
116.455
117.000
117.460
118.000
118.464
119.000
119.468

D L U R D

119.000
119.468
120.000
120.472
121.000
121.477
122.000
122.481
123.000
123.485
124.000
124.489

D L U R D

124.000
124.489
125.000
125.494
126.000
126.498
127.000
127.502
128.000
128.506
129.000
129.511

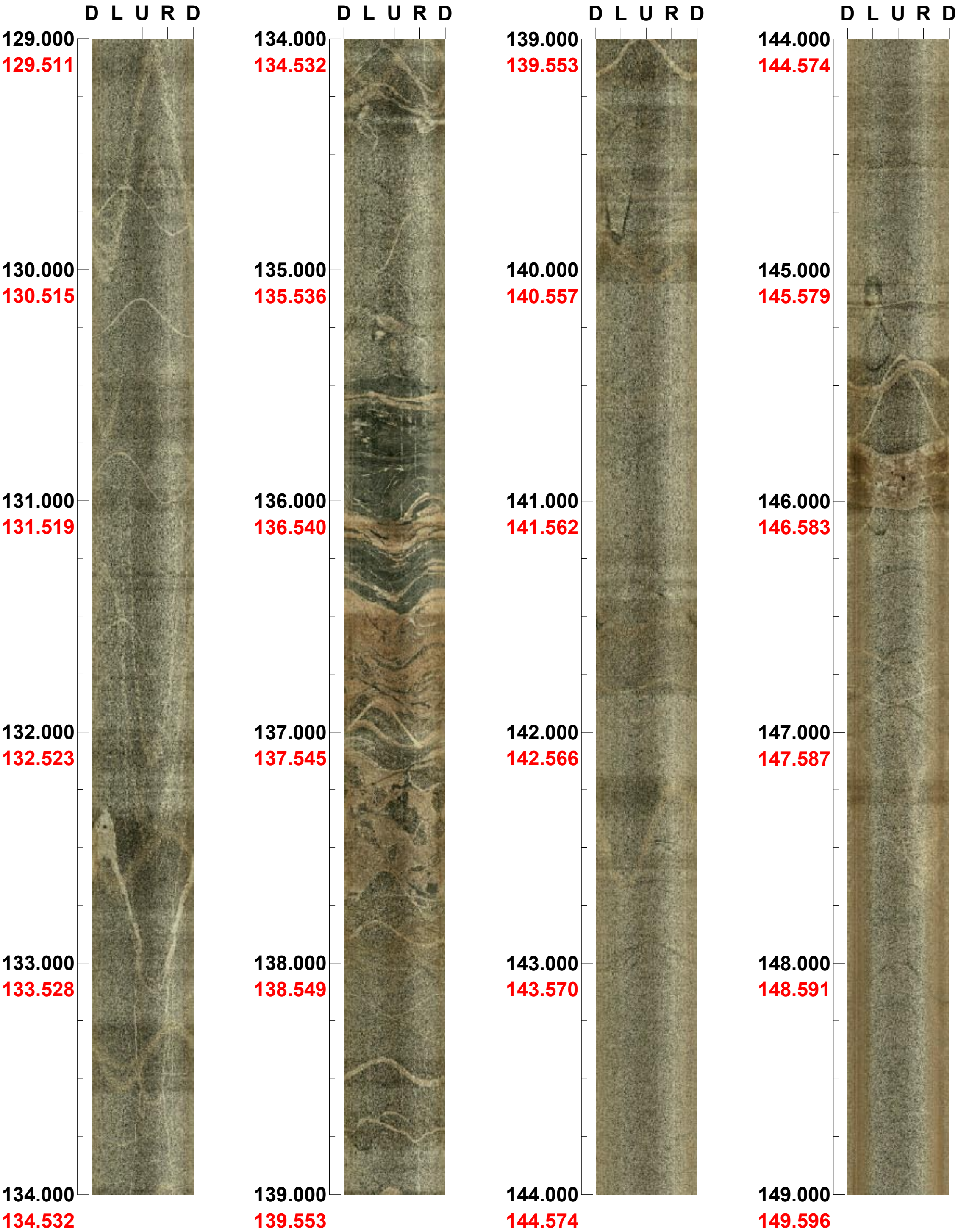


(6 / 8) Scale: 1/25 Aspect ratio: 100 %

Project name: Laxemar

Bore hole No.: HLX26 **Azimuth: 10** **Inclination: -60**

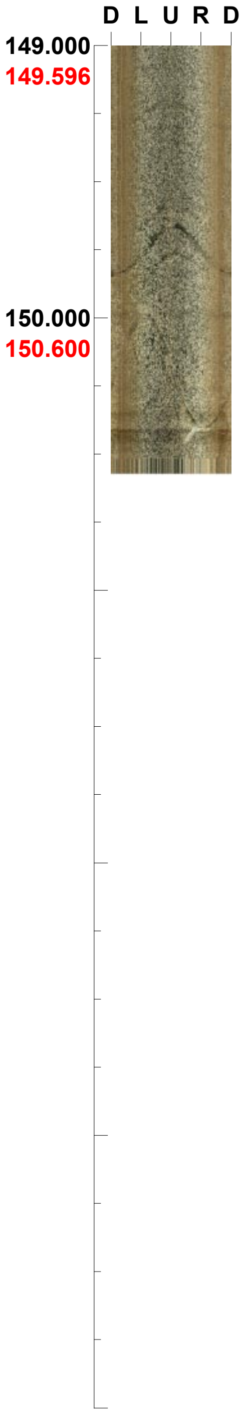
Depth range: 129.000 - 149.000 m



(7 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX26 **Azimuth: 10** **Inclination: -60**

Depth range: 149.000 - 150.569 m



(8 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

BIPS logging in HLX27, 6 to 159 m

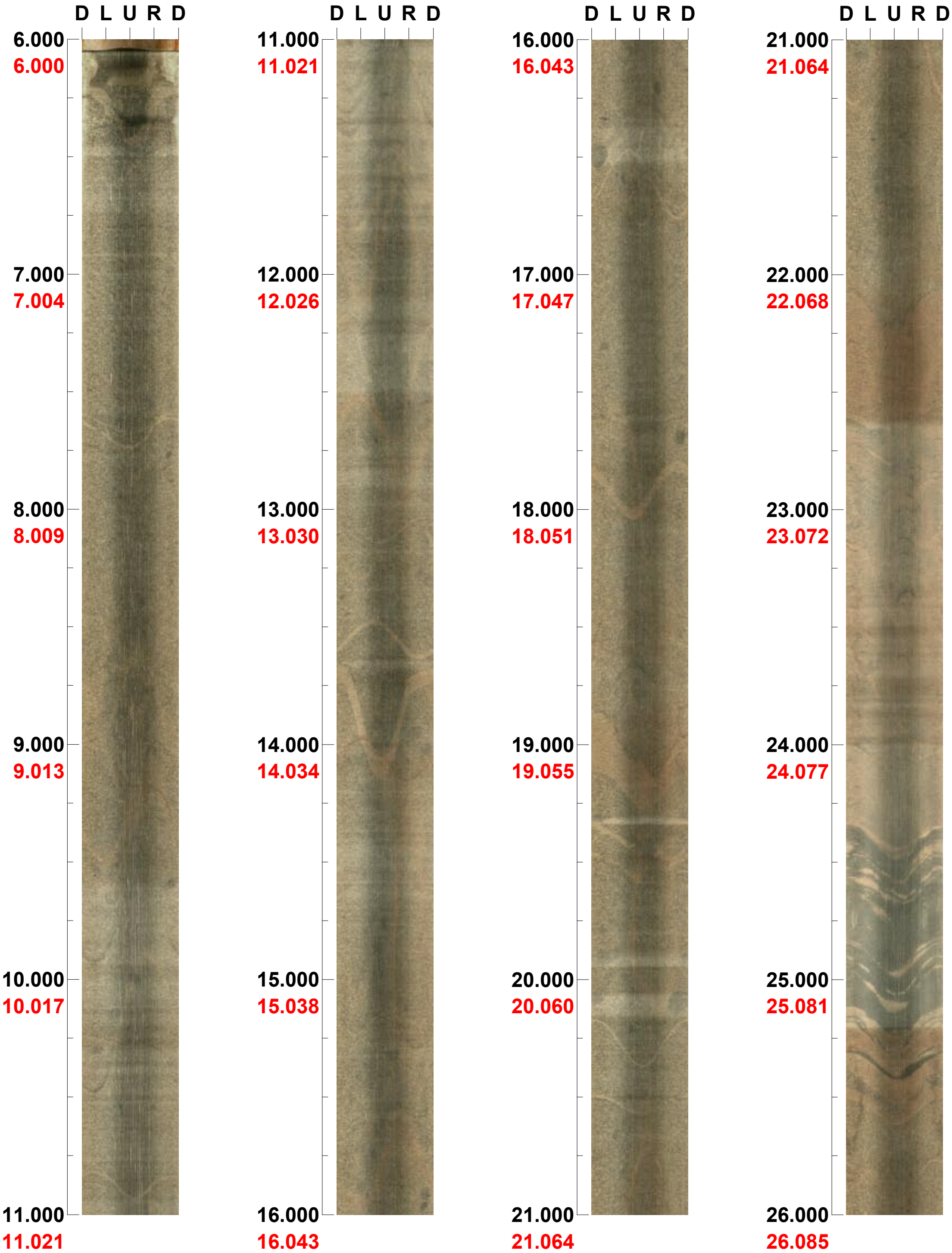
Project name: Laxemar

Image file	: c:\work\r5347s~1\hlx27\bips\hlx27.bip
BDT file	: c:\work\r5347s~1\hlx27\bips\hlx27.bdt
Locality	: LAXEMAR
Bore hole number	: HLX27
Date	: 04/10/19
Time	: 09:18:00
Depth range	: 6.000 - 159.314 m
Azimuth	: 190
Inclination	: -60
Diameter	: 131.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 100 %
Pages	: 8
Color	: +0 +0 +0

Project name: Laxemar

Bore hole No.: HLX27 **Azimuth: 190** **Inclination: -60**

Depth range: 6.000 - 26.000 m



(1 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX27 **Azimuth: 190** **Inclination: -60**

Depth range: 26.000 - 46.000 m

(2 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar

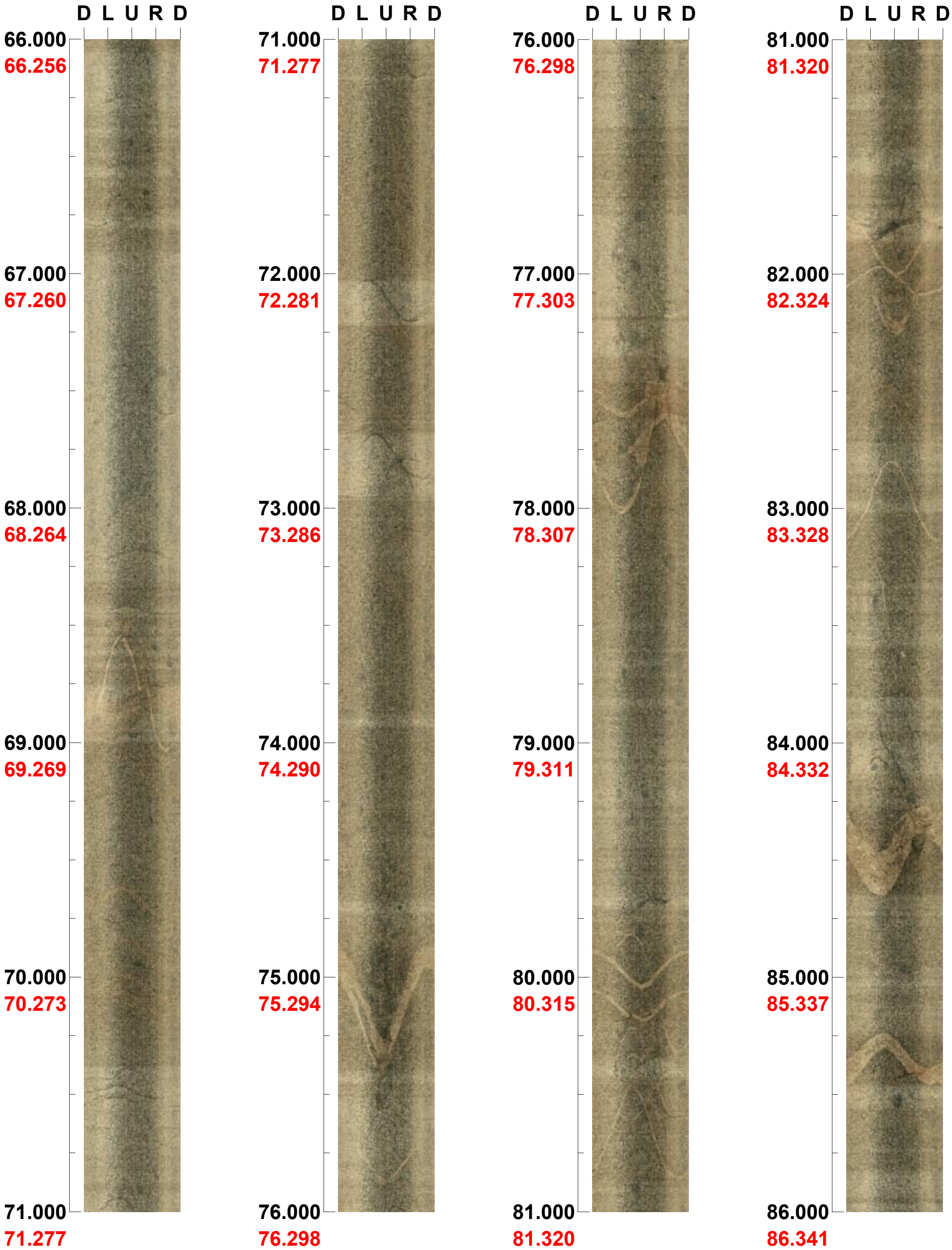
Bore hole No.: HLX27 **Azimuth: 190** **Inclination: -60**

Depth range: 46.000 - 66.000 m

(3 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX27 **Azimuth: 190** **Inclination: -60**

Depth range: 66.000 - 86.000 m

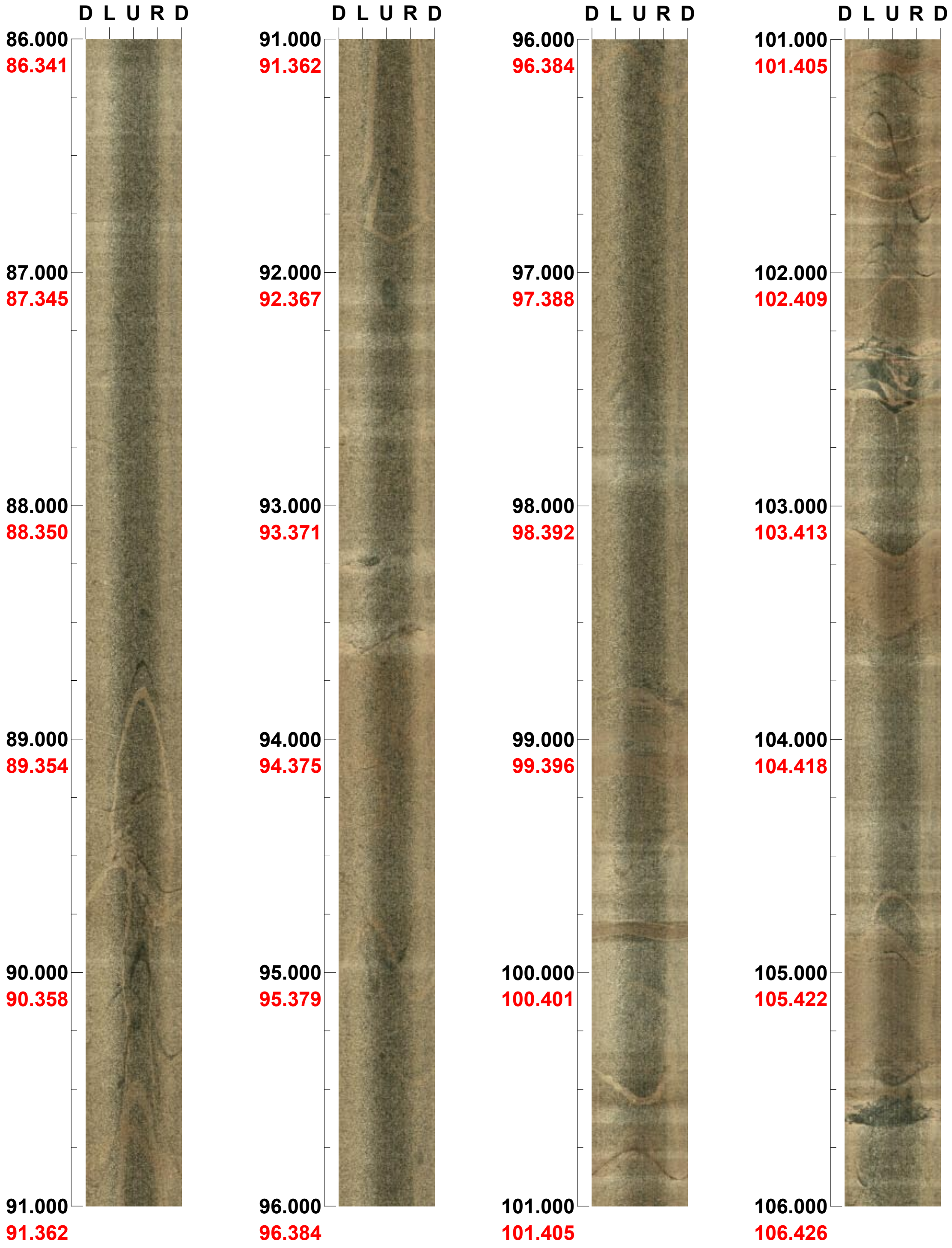


(4 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar

Bore hole No.: HLX27 **Azimuth: 190** **Inclination: -60**

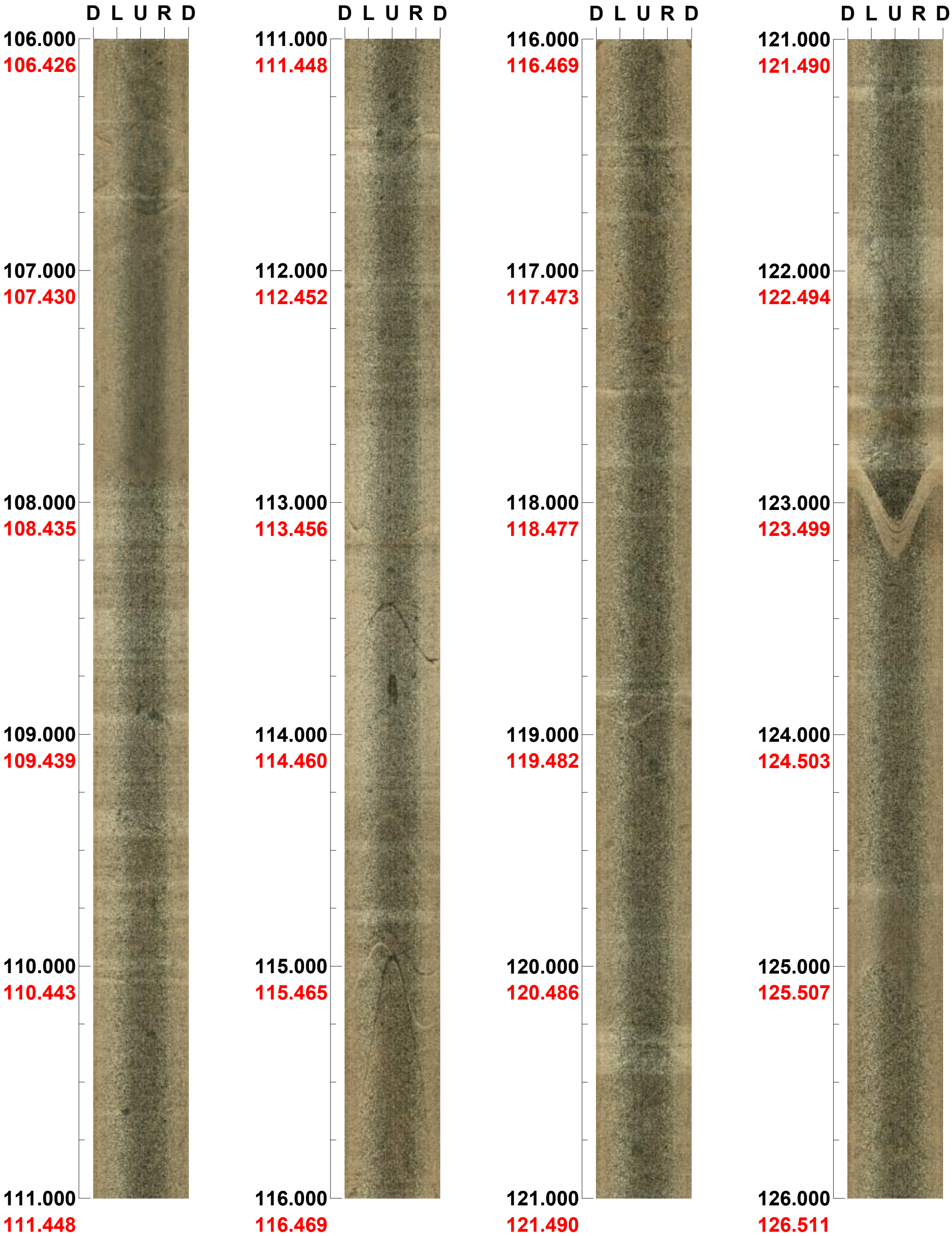
Depth range: 86.000 - 106.000 m



(5 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX27 Azimuth: 190 Inclination: -60

Depth range: 106.000 - 126.000 m



(6 / 8) Scale: 1/25 Aspect ratio: 100 %

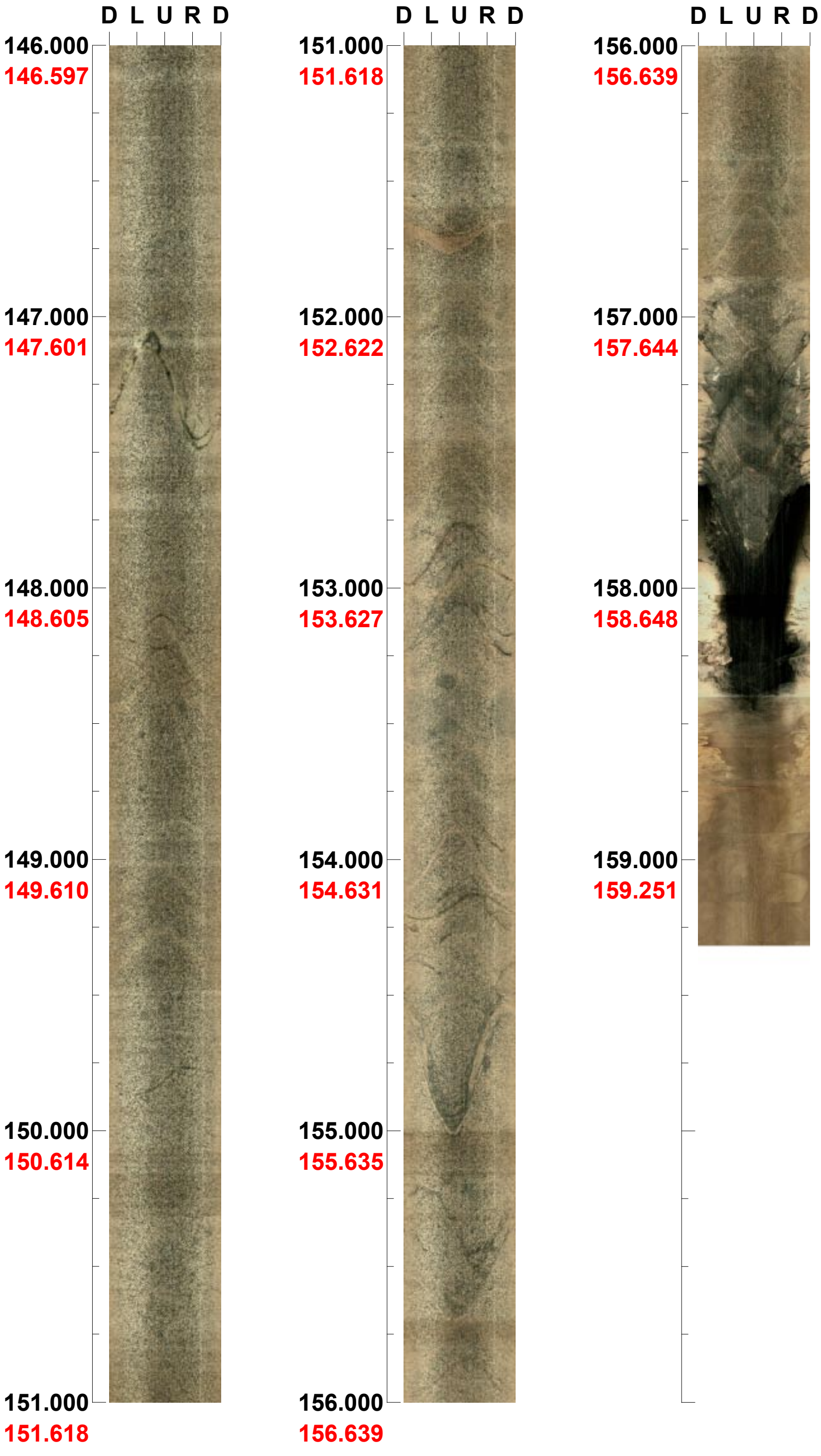
Project name: Laxemar
Bore hole No.: HLX27 **Azimuth: 190** **Inclination: -60**

Depth range: 126.000 - 146.000 m

(7 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX27 **Azimuth: 190** **Inclination: -60**

Depth range: 146.000 - 159.314 m



(8 / 8) **Scale: 1/25** **Aspect ratio: 100 %**

BIPS logging in HLX28, 6 to 143 m

Project name: Laxemar

Image file	: c:\work\r5347s~1\hlx28\bips\hlx28_a/b.bip
BDT file	: c:\work\r5347s~1\hlx28\bips\hlx28_a/b.bdt
Locality	: LAXEMAR
Bore hole number	: HLX28
Date	: 04/10/20
Time	: 06:47:00
Depth range	: 6.000 - 143.230 m
Azimuth	: 200
Inclination	: -60
Diameter	: 140.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 100 %
Pages	: 4
Color	: +0 +0 +0

Project name: Laxemar
Bore hole No.: HLX28 **Azimuth: 200** **Inclination: -60**

Depth range: 6.000 - 26.000 m

(1 / 4) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX28 **Azimuth: 200** **Inclination: -60**

Depth range: 26.000 - 46.000 m

(2 / 4) **Scale: 1/25** **Aspect ratio: 100 %**

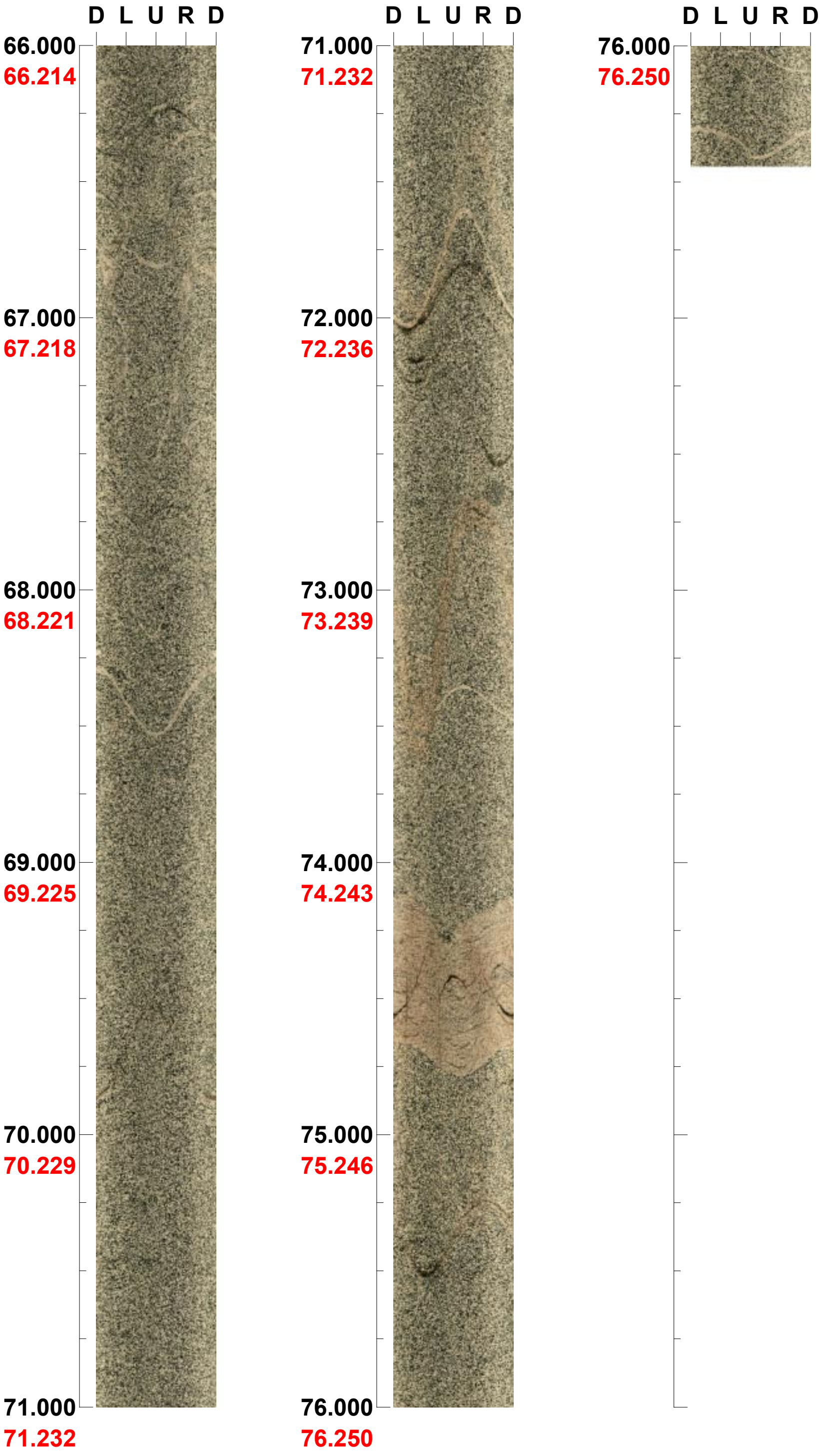
Project name: Laxemar
Bore hole No.: HLX28 **Azimuth: 200** **Inclination: -60**

Depth range: 46.000 - 66.000 m

(3 / 4) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX28 **Azimuth: 200** **Inclination: -60**

Depth range: 66.000 - 76.442 m

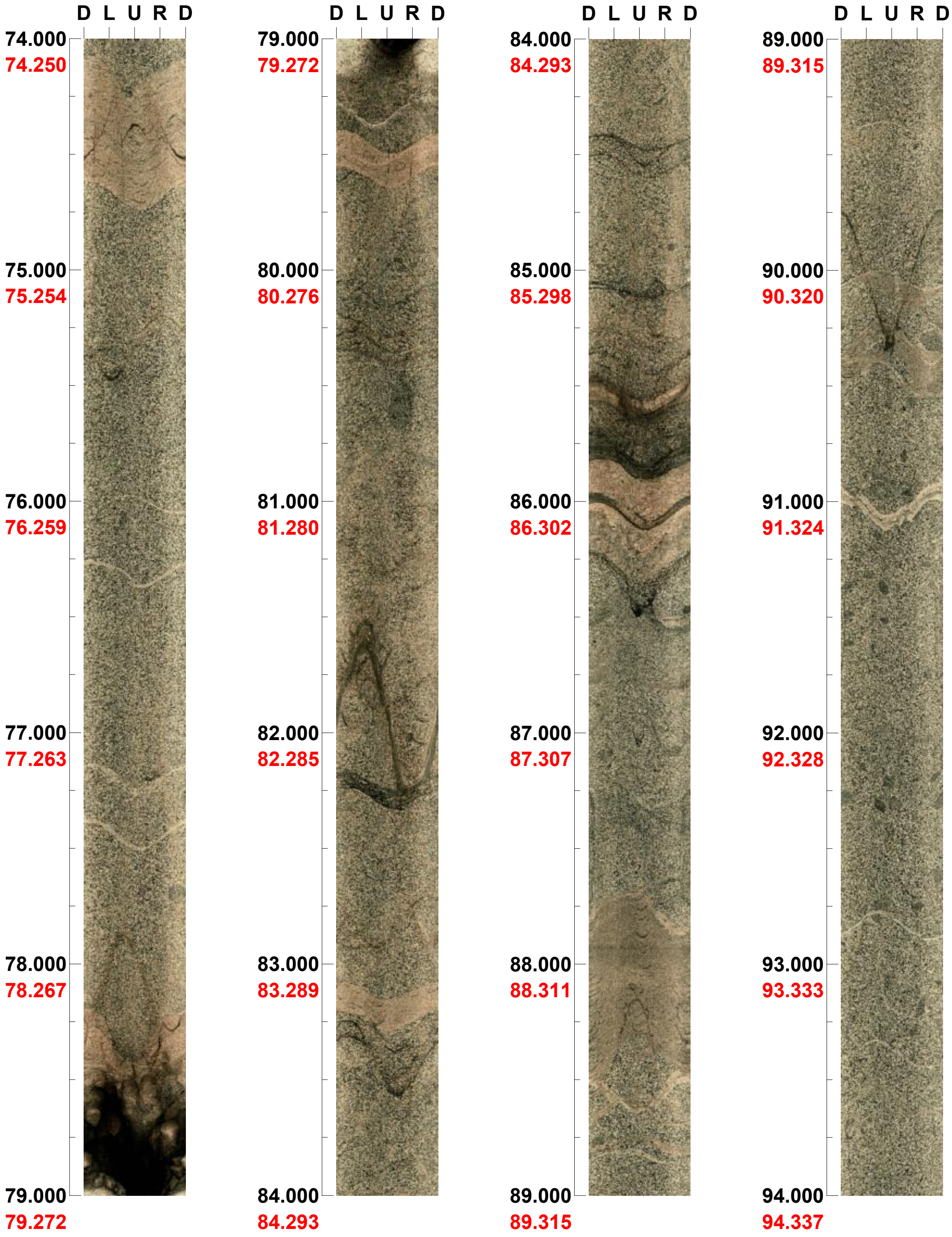


(4 / 4) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar

Bore hole No.: HLX28 **Azimuth: 200** **Inclination: -60**

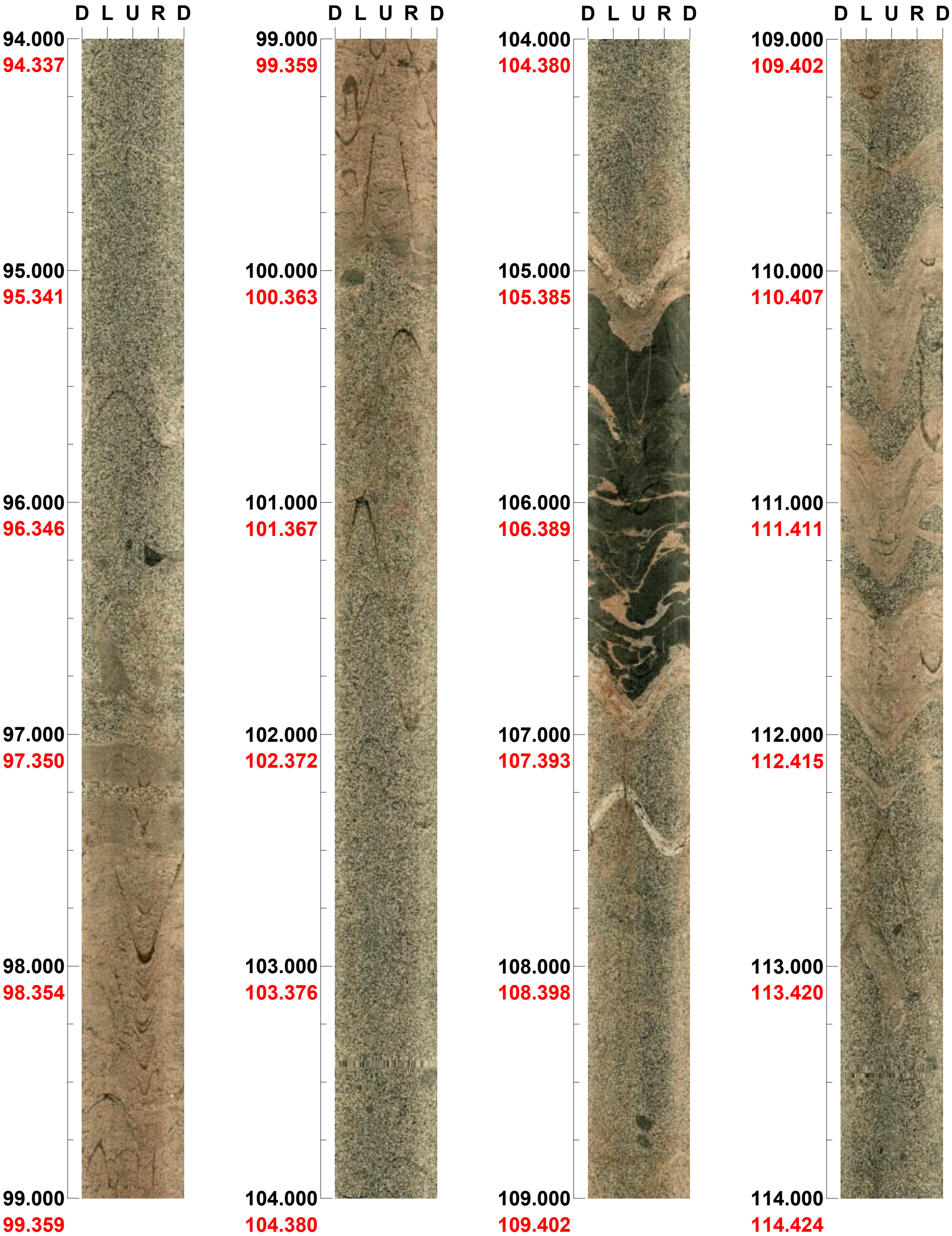
Depth range: 74.000 - 94.000 m



(1 / 4) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX28 **Azimuth: 200** **Inclination: -60**

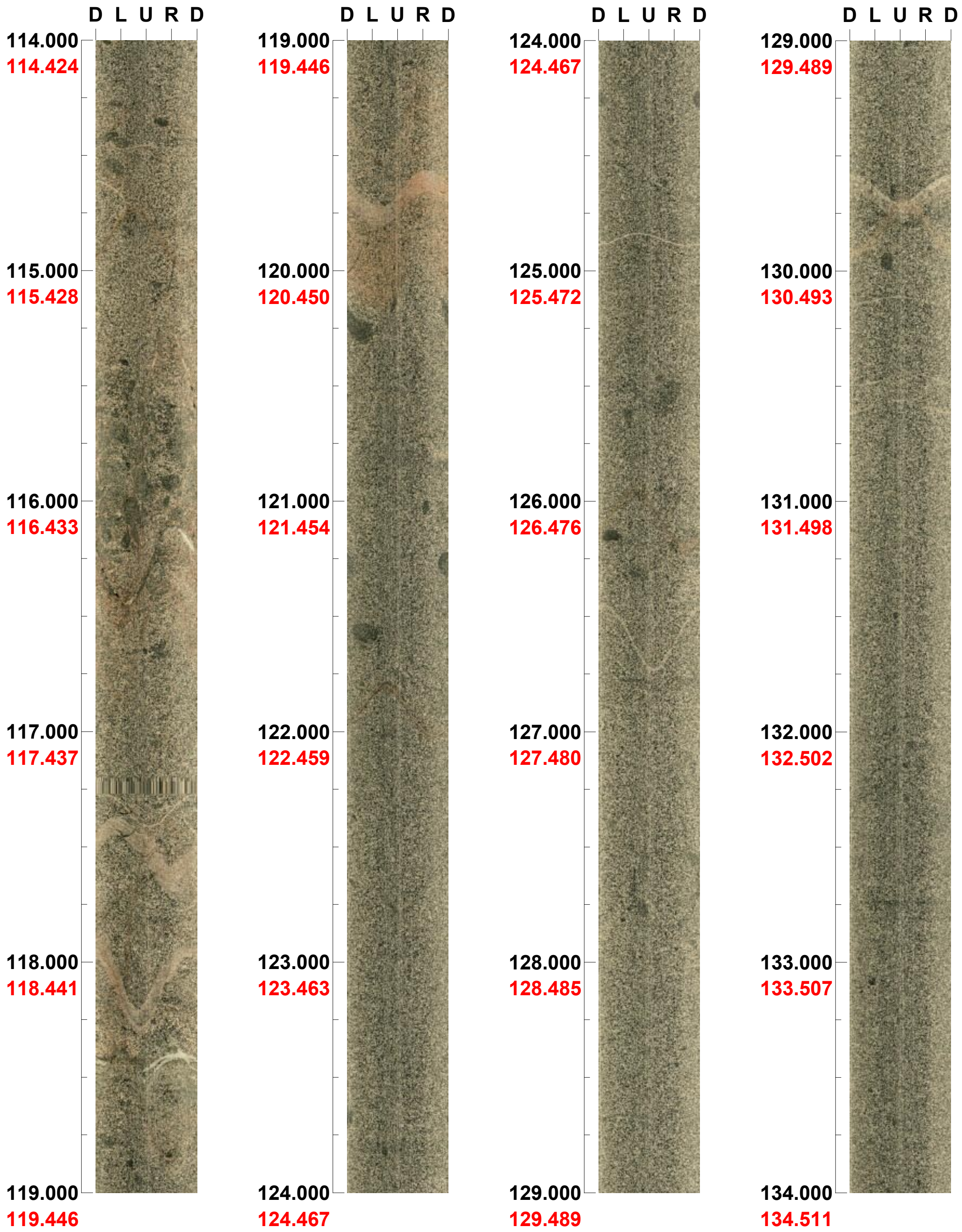
Depth range: 94.000 - 114.000 m



(2 / 4) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX28 **Azimuth: 200** **Inclination: -60**

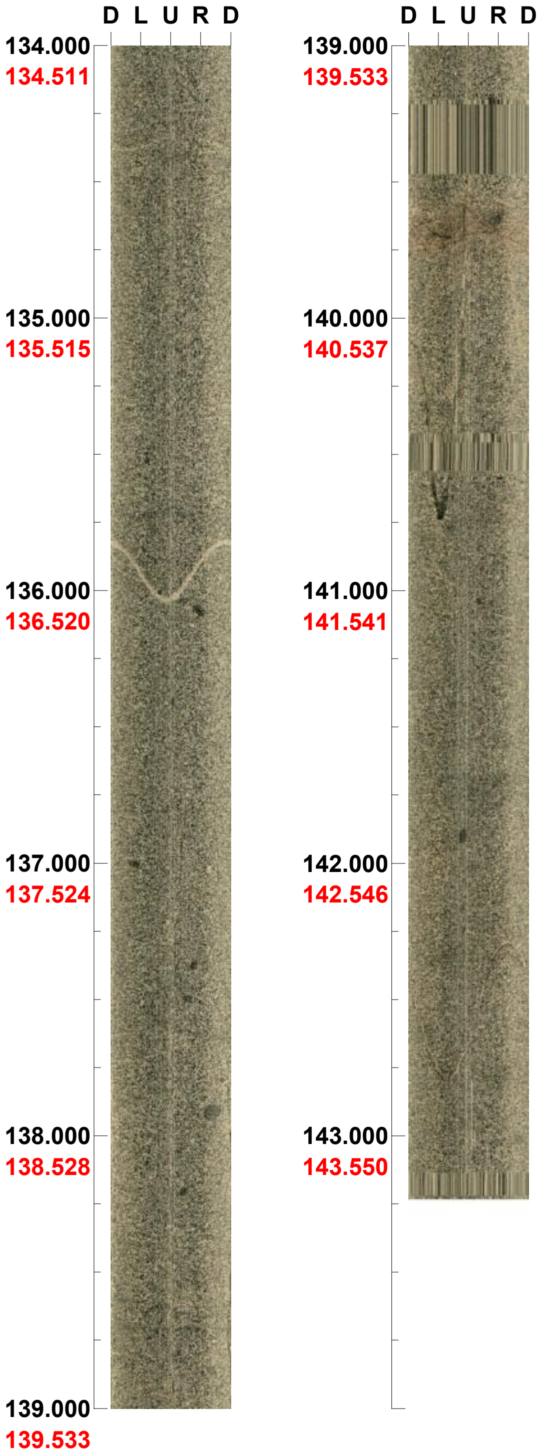
Depth range: 114.000 - 134.000 m



(3 / 4) **Scale: 1/25** **Aspect ratio: 100 %**

Project name: Laxemar
Bore hole No.: HLX28 **Azimuth: 200** **Inclination: -60**

Depth range: 134.000 - 143.230 m



(4 / 4) **Scale: 1/25** **Aspect ratio: 100 %**