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Forsmark site investigation

Geophysical borehole logging in borehole KFM01D

Uffe Torben Nielsen, Jørgen Ringgaard
RAMBØLL

August 2006

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Abstract

Geophysical borehole logging has been performed in borehole KFM01D situated in Forsmark, Sweden.

The objective of the survey is to determine the physical properties of the rock mass around the borehole, e.g. to determine rock types and quantify the fracture frequency and localise deformation zones in the rock. Geophysical borehole logging was used to measure changes in physical properties in the borehole fluid and the bedrock surrounding the borehole.

The logging in KFM01D was recorded from 91 m to 800 m.

The present report comprises a description of the applied equipment and the performed logging program, the fieldwork, data delivery and a presentation and discussion of the results.

Composite sheets of all the processed logs are included in Appendix 1.

Sammanfattning

Geofysisk borrhålsloggning har genomförts i borrhålen KFM01D i Forsmark.

Syftet med geofysisk borrhålsloggning är att bestämma bergets fysikaliska egenskaper för att bestämma bergartsfördelningen i det genomborrade bergpartiet samt att kvantifiera sprickfrekvensen och att lokalisera deformationszoner. Med geofysisk borrhålsloggning mäts bergets och borrhålsvattnets fysikaliska egenskaper i borrhålet och omgivande berg.

Den geofysiska borrhålsloggningen genomfördes i KFM01D från 91 m till 800 m.

Rapporten beskriver använd utrustning, genomfört loggningsprogram, fältarbete, leverans av data och en diskussion av resultatet.

Processerade loggar presenteras i Appendix 1.

Contents

1 Introduction 7

2 Objective and scope 11

3 Equipment 13

4 Execution 15
4.1 General 15
4.2 Nonconformities 15

5 Results 17
5.1 Presentation 17
5.2 Orientation, alignment and stretch of logs 18
5.2.1 Orientation of images 18
5.2.2 Overlapping data 18
5.2.3 Alignment of data 18
5.2.4 Stretch of logs 18
5.2.5 Removing of data 18
5.2.6 Repicking of sonic log 18
5.3 Calculated log curves 19
5.3.1 Calculation of coordinates 19
5.4 Borehole KFM01D 20

6 Data delivery 21

Appendix 1 Borehole KFM01D, drawing no. 1.1, borehole logs 23

1 Introduction

This document reports the results gained by the geophysical borehole logging in the borehole KFM01D, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-06-013 (SKB internal controlling document). In Table 1-1 controlling documents for performing this activity are listed.

All measurements were conducted by RAMBØLL during the period March 8 and 9 2006. The borehole was recorded from Top Of Casing (TOC) to the bottom of the borehole. The technical data from the borehole is shown in Table 1-2. The location of the borehole is shown in Figure 1-1.

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 internal controlling documents).

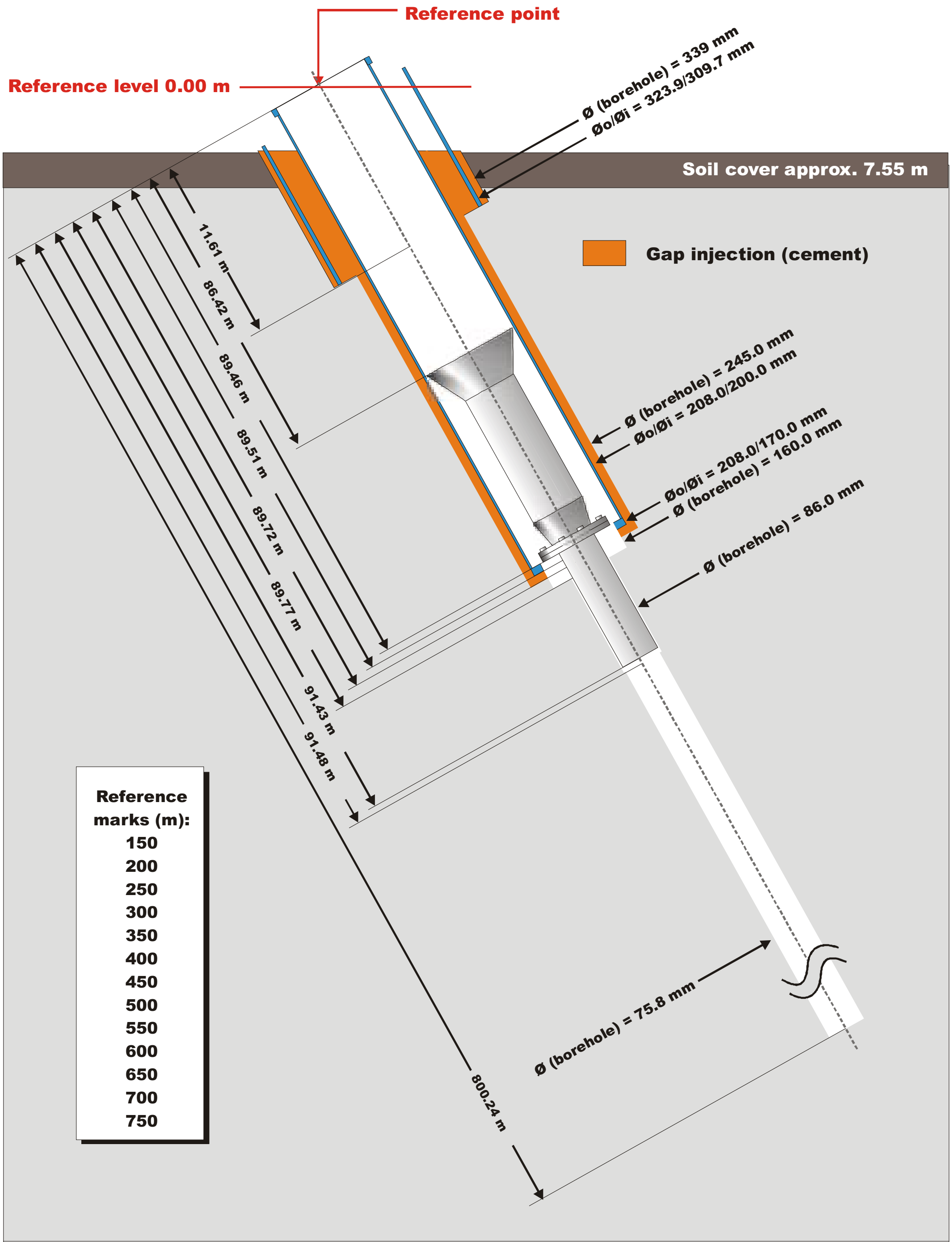
Activity plan	**Number**	**Version**
Geofysisk borrhålsloggning i kärnborrhålen KFM01D.	AP PF 400-06-013	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för geofysisk borrhålsloggning.	SKB MD 221.002	2.0
Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål.	SKB MD 224.001	1.0

Table 1-2. Technical data for the borehole.

Borehole Parameter	**KFM01D**
Co-ordinates (RT90)	6699542.07 1631404.52
Elevation (RHB70)	2.95
Azimuth	35.04
Inclination (from horizontal)	–54.90
Length (m)	800.24
Casing (m)	91.16
Borehole diametre (mm)	75.8

Figure 1-1. *General overview over the Forsmark area showing the location of the borehole KFM01D.*

Technical data
Borehole KFM01D



Drilling reference point

Northing: 6699542.07 (m), RT90 2,5 gon V 0:-15

Easting: 1631404.52 (m), RT90 2,5 gon V 0:-15

Elevation: 2.95 (m), RHB 70

Orientation

Bearing (degrees): 35.04°

Inclination (degrees): -54.90°

Borehole

Length: 800.24 m

Percussion drilling period

Drilling start date: 2005-11-21

Drilling stop date: 2005-12-05

Core drilling period

Drilling start date: 2005-12-17

Drilling stop date: 2006-02-18

Rev 2006-05-24

Figure 1-2. *Technical description of borehole KFM01D.*

2 Objective and scope

The objective of the survey is to both receive information of the borehole itself, and from the rock mass around the borehole. Geophysical borehole logging was used to measure changes in physical properties in the borehole fluid and the bedrock surrounding the borehole. Acoustic televiewer was used for determination of the deviation of the borehole (azimuth and inclination) as well as to determine the length marks in the borehole.

This field report describes the equipment used as well as the measurement procedures. Geophysical borehole logging data is presented in Appendix 1.

3 Equipment

The geophysical borehole logging program were performed with 7 multi-tool probes and resulted in a suite of 19 log types, listed in Table 5-1. The tools and recorded logs are listed in Table 3-1.

Table 3-1. Logging tools and logs recorded.

Tool	Recorded logs	Dimension	Source detector spacing and type	Tool position in borehole	Tool used in borehole
Century 8144 Normal resistivity	Normal resistivity (16 & 64 inch), single point resistance and natural gamma.	237·5.3 cm			Yes
Century 8622 Magnetic susceptibility	Magnetic susceptibility, natural gamma.	203·4.1 cm			Yes
Century 9042 Fluid temperatur and fluid resistivity	Fluid temperatur, fluid resistivity and natural gamma.	137·4.1 cm			Yes
Century 9072 3 m focused guard	3 m focused guard log resistivity and natural gamma.	310·6.4 cm			Yes
Century 9139 Compensated gamma density	Compensated Gamma density, natural gamma, 140 cm focused guard log resistivity, 1-arm caliper.	380.3·5.6 cm	20.3 cm 125 m 200 mCi Cs137	Sidewall Gamma source focused.	Yes
Century 9310 Sonic	Full wave form travel-time providing P & S-wave velocity picking, compensated P-wave travel-time and natural gamma.	300·6.0 cm	Near 91.4 cm Far 121.9 cm	Centralized.	Yes
RG 25 112 000 HiRAT Acoustic televiewer	Full waveform acoustic amplitude and travel-time, 360° orientated acoustic image, 360° very high resolution caliper, borehole azimuth and dip and natural gamma.	246·4 cm		Centralized.	Yes

4 Execution

4.1 General

In general the measurement procedures follow the SKB method description (MD 221.002, SKB internal controlling document). The logging program was executed in the period March 8 to 9, 2006. All relevant logging events are described in the daily report sheets delivered to SICADA and are traceable by the activity plan number.

The fluid resistivity and temperature logs are recorded in downward direction, as the first log run. All other log types are recorded running the tool in upward direction in the borehole.

The applied logging equipment was calibrated and cleaned before arriving at the site according to SKB cleaning level 2 (SKB internal controlling document SKB MD 600.004). Furthermore, all equipment was wiped with alcohol before it was lowered into the borehole.

For control, each log run is normally recorded both in down and in upward direction using the down run as a repeat section. For logging tool 9139 recording a repeat section in upward direction controls the data. The depth of the probe in the borehole is shown on both the recording computer and the winch. On the winch the tension of the cable is also shown. The winch will automatically stop, if the tension changes rapidly. The tension was recorded on all log runs using Century equipment, except tool 9310.

All data was recorded with max 10 cm sample interval. The speed of the logging for the 9139 tool was 5 m/min, for the 8622 tool 20 m/min and for all other tools 10 m/min, except for the HiRAT Acoustic tool where the speed was 2 m/min.

4.2 Nonconformities

The logging has been performed in accordance with the activity plan AP PF 400-06-013.

5 Results

5.1 Presentation

All relevant logging events were described in the daily report sheets, which were delivered separately.

Logs presented in Appendix 1 (drawings no. 1.1) are presented in Table 5-1.

Table 5-1. Logs presented in drawings no. 1.1, Appendix 1.

Log	Log name short	Unit	Tool
Fluid temperature	TEMP(FL)	Deg C	9042
Fluid resistivity	RES(FL)	Ohm-m	9042
Normal resistivity 16 inch	RES(16N)	Ohm-m	8144
Normal resistivity 64 inch	RES(64N)	Ohm-m	8144
Lateral resistivity	LATERAL	Ohm-m	8144
Single point resistance	SPR	Ohm	8144
Self potential	SP	mV	8144
Magnetic susceptibility	MAGSUSCEP	$SI \cdot 10^{-5}$	8622
Caliper, 1-arm	CALIPER1	mm	9139
Gamma-gamma density	DENSITY	kg/m^3	9139
Focused guard log resistivity, 127 cm	RES(SG)	Ohm-m	9139
Natural gamma	GAM(NAT)	µR/h	9072
Focused guard log resistivity, 300 cm	RES(DG)	Ohm-m	9072
P-wave velocity	P-VEL	m/s	9310
Full wave form, near receiver	AMP(N)	µs	9310
Full wave form, far receiver	AMP(F)	µs	9310
Caliper, high resolution. 360°	CALIPER 3D	mm	HiRAT
High resolution 1D Caliper	CALIPER MEAN	mm	HiRAT
Borehole azimuth magnetic north	AZIMUTH MN	Deg	HIRAT
Borehole inclination from horizontal	DIP	Deg	HIRAT
360° orientated acoustic travel time	TRAVEL TIME	100 ns	HiRAT
360° orientated acoustic travel time	AMPLITUDE	–	HiRAT

5.2 Orientation, alignment and stretch of logs

5.2.1 Orientation of images

The orientation of the results from the HiRAT Acoustic tool, are processed in the tool while recording, using the magnetometers and accelerometers in the tool.

5.2.2 Overlapping data

If the log data from one probe have been recorded in more than one file, the files are merged using events in both files. Overlapping in data is always used from the topmost-recorded file (overlapping data are never the mean value from two log runs).

5.2.3 Alignment of data

In order to obtain an exact depth calibration, the track marks made while drilling are used. In boreholes without track marks, gamma events in the top and the bottom of the borehole are used. The connection between the track marks and the logs is obtained from the HiRAT Acoustic tool. The depths from the track marks and from the HiRAT tool are used to make a new depth scale in WellCAD. All log files are shifted using the new depth scale.

5.2.4 Stretch of logs

There is a minor difference in the depth registration between up- and down runs for the used winch. The size of the defect is about 1.5 m/km. To compensate for this the logs are stretched using another new depth scale for each tool. The depth scale is made by using gamma events from the tool compared with the same gamma events from the HiRAT tool. The events in both files are matched, and the new depth scale is made and added to the log. The bottom of the borehole is considered in stretching the logs in case that no data will occur below the bottom of the borehole.

5.2.5 Removing of data

The processing of the data includes removing of spikes, negative and unrealistic values and data in the casing.

5.2.6 Repicking of sonic log

The sonic velocity is normally calculated using an automatic picking routine in the sonic tool, 9310. In inclined boreholes the routine is often picking the wrong arrivals, due to so-called “road noise”. Therefore the sonic logs have been manually repicked in WellCAD using the full wave signal.

5.3 Calculated log curves

The different logs are calculated as described in Table 5-2.

5.3.1 Calculation of coordinates

To convert the measured azimuth and inclination to grid-coordinates, one needs to take into account the magnetic declination at the site at the time of data acquisition. The actual declination was found by means of the current International Geomagnetic Reference Field (IGRF). The actual values can be found below. Disturbances from solar storms etc. were not taken into account. By means of the "Radius Of Curvature" method implemented in WellCad, the azimuth and inclination were converted to northing, easting and TVD coordinates relative to the top of the borehole. In the same calculation, the magnetic declination was added. Finally, the relative coordinates were added to the given coordinate in RT90 for the top of the borehole. The coordinates were calculated from 5 m below the casing bottom.

Table 5-2. Calculated log curves.

Log	Description of log calculation
Caliper, 1-arm	The Caliper was converted from [cm] to [mm] units by multiplying [cm] with 10.
Gamma-gamma density	The Gamma-gamma was converted from [g/cm^3] to [kg/m^3] units by multiplying with 1,000.
Focused guard log resistivity, 140 cm	–
Natural gamma	The natural gamma log was converted from CPS to μR/h by multiplying the constant 0.077. This constant was computed from the logs previously performed in borehole KLX02 located in Oskarshamn.
Fluid temperature	–
Fluid resistivity	–
Normal resistivity 16 inch	–
Normal resistivity 64 inch	–
Lateral resistivity	–
Single point resistance	–
Self-potential	–
Focused guard log resistivity, 300 cm	–
P-wave velocity	The P-VEL velocity is calculated using the difference in distance between the far and near receiver divided by time difference between the first arrival from the far and near signal. (121.9 cm–91.4 cm)/(Time(far)–Time(near)).
Full wave form, near receiver	–
Full wave form, far receiver	–
Magnetic susceptibility	The magnetic susceptibility was converted for CGS units to SI units by multiplying the CGS value by 4π.
Caliper, high resolution. 360°. CALIPER 3D	The Caliper 3D is calculated using the acoustic travel time and the velocity in the borehole fluid. The velocity in the fluid is calculated using the fluid temperature and fluid conductivity.
High resolution 1D Caliper CALIPER MEAN	The Caliper mean is calculated using the mean travel time from the acoustic televiewer, the fluid temperature, fluid velocity and the internal travel time in the acoustic televiewer.
Borehole azimuth magnetic north	See 5.3.1
Borehole Inclination from lateral	See 5.3.1
360° orientated acoustic travel time	–
360° orientated acoustic amplitude	–

5.4 Borehole KFM01D

In order to obtain an exact depth calibration in borehole KFM01D, the reference track marks made while drilling are used. The correlation between the track marks and the logs is obtained from the HiRAT Acoustic tool.

The reference track marks in the borehole and the recorded track marks from the HiRAT are observed in the following depths, Table 5-3.

To compensate for the difference between the reference track marks and the recorded track marks the logs are stretched. The result from the stretching is a new depth scale. The new depth scale is applied to the HiRAT file. In this way a perfect match between given depths of the reference marks and the recorded data is obtained. By means of alignment of the observed gamma events in KFM01D, between all log runs, the obtained reference mark correlation is transferred to the other logs.

The complete log suite for borehole KFM01D is presented as composite log sheets in drawing 1.1 in Appendix 1. The logs presented in drawing no. 1.1 are listed in Table 5-1.

Table 5-3. The reference track marks in the borehole and the recorded track marks from the HiRAT in borehole KFM01D.

Reference mark	HIRAT recorded
150.00	150
200.00	200.166
250.00	250.304
300.00	300.46
350.00	350.61
400.00	400.74
450.00	450.87
500.00	501.012
550.00	551.18
600.00	601.307
650.00	651.484
700.00	701.622
750.00	751.776

6 Data delivery

Geophysical logging data from the measurements, recorded in Century and Robertson format, were delivered directly after the termination of the field activities. The recorded data files used in the processing have also been delivered in WellCAD format, Table 6-1.

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

The processed files shown on the drawings have been delivered in WellCAD, Table 6-2, and as excel files (one for each borehole) in SICADA format, Table 6-3.

Table 6-1. Recorded log files in Century or Robertson format used for processing.

Borehole	Probe	Log direction	WellCAD File	Description
KFM01D	8144	Down	KFM01D_03-08-06_07-10_8144C_.10_1.30_800.70_ORIG.log	Start Depth: 1.3 m End Depth: 800.7 m
KFM01D	8622	Up	KFM01D_03-09-06_12-42_8622C_.1_-1.30_799.20_ORIG.log	Start Depth: 799.2 m End Depth: –1.3 m
KFM01D	9042	Down	KFM01D_03-07-06_16-00_9042C_.10_1.20_801.00_ORIG.log	Start Depth: 1.2 m End Depth: 801 m
KFM01D	9072	Up	KFM01D_03-08-06_18-08_9072C_.02_0.28_800.04_ORIG.log	Start Depth: 800.04 m End Depth: 0.28 m
KFM01D	9072	Up	KFM01D_03-07-06_18-41_9072C_.10_0.30_800.30_ORIG.log	Start Depth: 800.3 m End Depth: 0.3 m
KFM01D	9139	Up	KFM01D_03-09-06_09-36_9139A_.02_81.54_799.58_ORIG.log	Start Depth: 799.58 m End Depth: 81.54 m
KFM01D	9310	Up	KFM01D_03-09-06_06-59_9310C2_.10_-0.20_799.00_ORIG.log	Start Depth: 799 m End Depth: –0.2 m
KFM01D	HiRAT	Up	KFM01D_HiRAT_180pixels_up_run4.HED	Start Depth: 380 m End Depth: 1 m
KFM01D	HiRAT	Up	KFM01D_HiRAT_180pixels_up_run3.HED	Start Depth: 797 m End Depth: 373 m

Table 6-2. Drawing files in WellCad format.

Borehole	Drawing	WellCad file
KFM01D	1.1	KFM01D_Presentation.WCL

Table 6-3. Data files in SICADA format.

Sheet	Comment
"Borehole"_CALIPER1_GP040 - Caliper logging.xls	
"Borehole"_CALIPER MEAN_GP041 - 3-D caliper.xls	
"Borehole"_TEMP(FL)_RES(FL)_GP060 – Fluid temperature and resistivity logging.xls	
"Borehole"_DENSITY_GP090 – Density logging.xls	
"Borehole"_MAGSUSCEP_GP110 - Magnetic susceptibility logging.xls	
"Borehole"_GAM(NAT)_GP120 - Natural gamma logging.xls	
"Borehole"_SPR_GP150 - Single point resistance logging.xls	
"Borehole"_RES(64N)_GP160 - Resistivity, normal 1.6 m (64 in).xls	
"Borehole"_RES(MG)_GP161 - Resistivity, focused 140 cm.xls	
"Borehole"_RES(DG)_GP162 - Resistivity, focused 300 cm.xls	
"Borehole"_LATERAL_GP163 - Resistivity, lateral 1.6-0.1 m.xls	
"Borehole"_RES(16N)_GP164 - Resistivity, normal 0.4 m (16 in).xls	
"Borehole"_P-VEL_GP175 - Fullwave sonic.xls	
"Borehole"_GP830 - Acoustic televiewer.xls	
"Borehole"_SP_GP180 - Self potential logging.xls	

Appendix 1

Borehole KFM01D, drawing no. 1.1, borehole logs

Borehole No. KFM01D

Co-ordinates in RT90 2,5 gon V 0:-15

Northing: 6699542.07m Easting: 1631404.52m Elevation: 2.95m, RHB70

Diameter:	75.8mm
Reaming Diameter:	245mm
Outer Casing:	
Inner Casing:	86mm
Borehole Length:	800.24m
Cone:	
Inclination at ground surface:	-54.90°
Azimuth:	35.04° GN
Comments:	

Borehole logging programme

Name	Description	Tool	Unit
CALIPER1	Caliper, 1-arm	9030/9139	mm
DENSITY	Gamma-gamma density	9030/9139	kg/m³
RES(MG)	Focused guard log resistivity, 140cm	9030	ohm-m
GAM(NAT)	Natural gamma	9072	μR/h
TEMP(FL)	Fluid temperature	9042	deg C
RES(FL)	Fluid resistivity	9042	ohm-m
RES(DG)	Focused guard log resistivity, 300cm	9072	ohm-m
P-VEL	P-wave velocity	9310	m/s
AMP(N)	Full wave form, near receiver	9310	μs
AMP(F)	Full wave form, far receiver	9310	μs
MAGSUSCEP	Magnetic susceptibility	8622	SI*10-5
CALIPER 3D	Caliper, high resolution 360 degrees	HiRAT	mm
CALIPER MEAN	High resolution 1D caliper	HiRAT	mm
AZIMUTH MN	Borehole azimuth magnetic north	HiRAT	deg
DIP	Borehole inclination from horizontal	HiRAT	deg
TRAVEL TIME	360 degrees orientated acoustic travel time	HiRAT	100 ns
AMPLITUDE	360 degrees orientated acoustic amplitude	HiRAT	-
THORIUM	Spectral gamma, Thorium component	9080	PPM
URANIUM	Spectral gamma, Uranium component	9080	PPM
POTASSIUM	Spectral gamma, Potassium component	9080	percent
RES(16N)	Normal resistivity 16 inch	8144	ohm-m
RES(64N)	Normal resistivity 64 inch	8144	ohm-m
LATERAL	Lateral resistivity	8144	ohm-m
SPR	Single point resistivity	8144	ohm
SP	Self Potential	8144	mV
RES(SG)	Focused guard log resistivity, 128 cm	9139	ohm-m

Rev.	Date	Drawn by	Control	Approved
0	2006-03-13	JRI	UTN	UTN

Job 547310A

Scale 1:500

RAMBØLL

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SKB geophysical borehole logging
Borehole KFM01D

Presentation

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Drawing no.:
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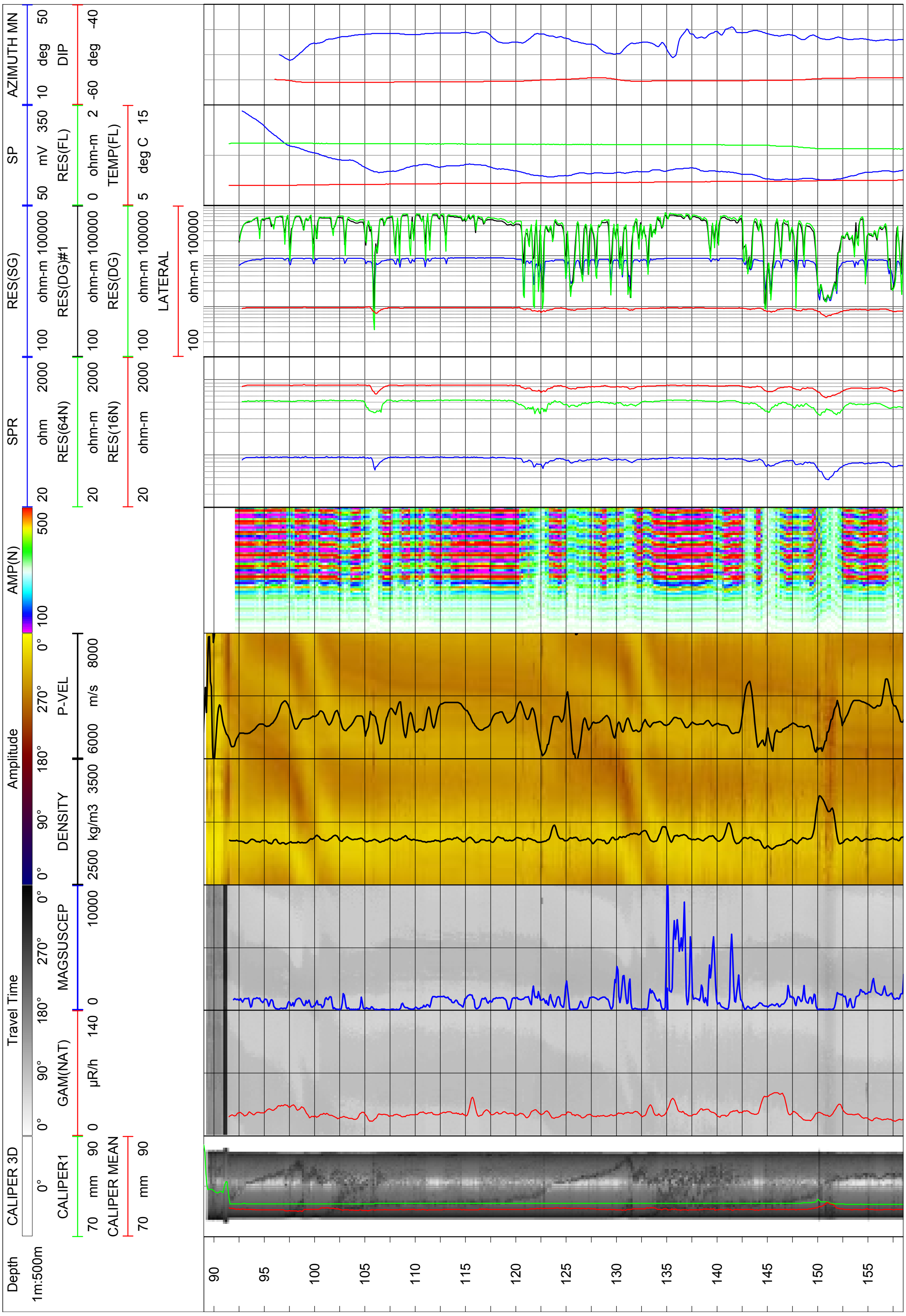
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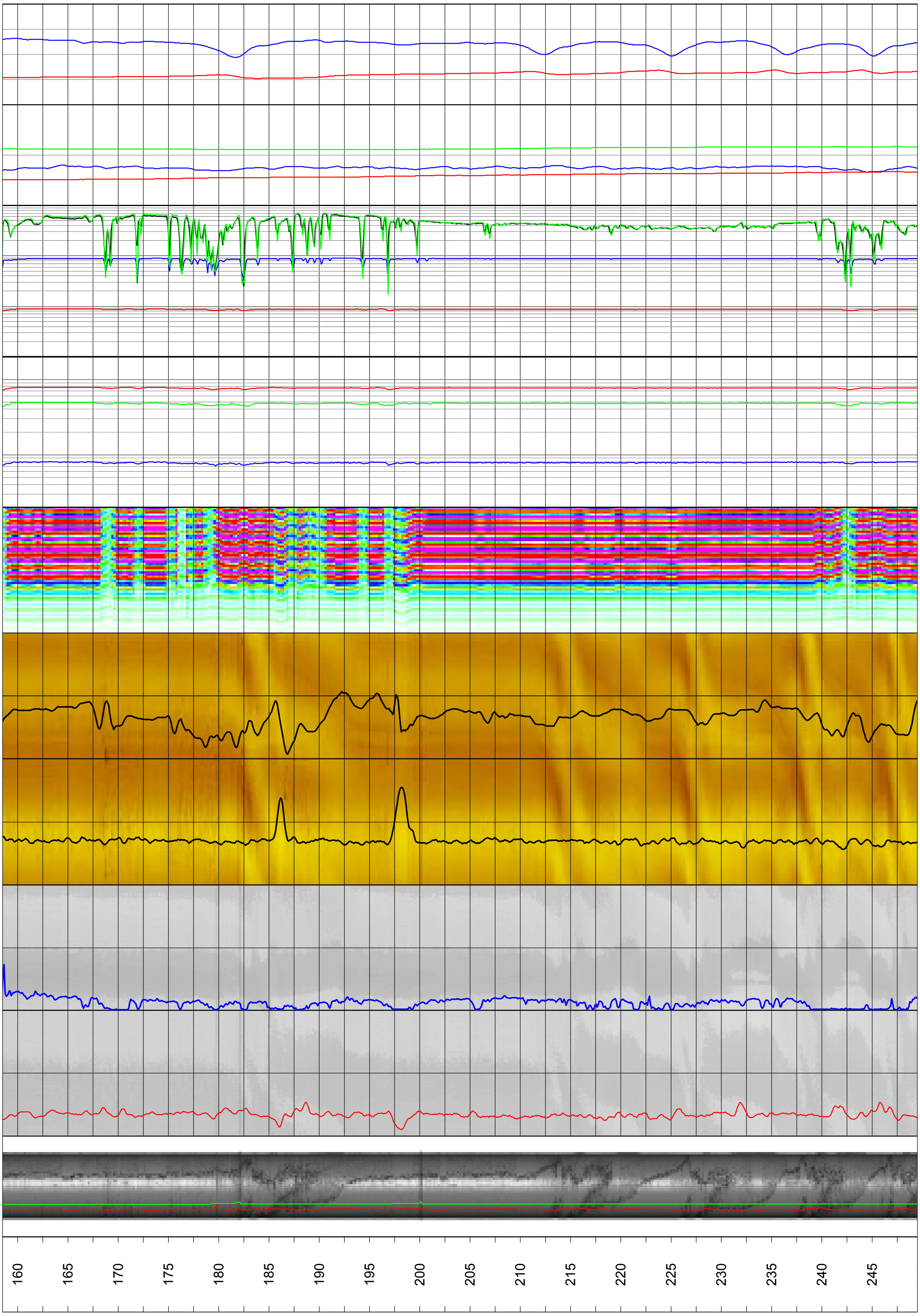
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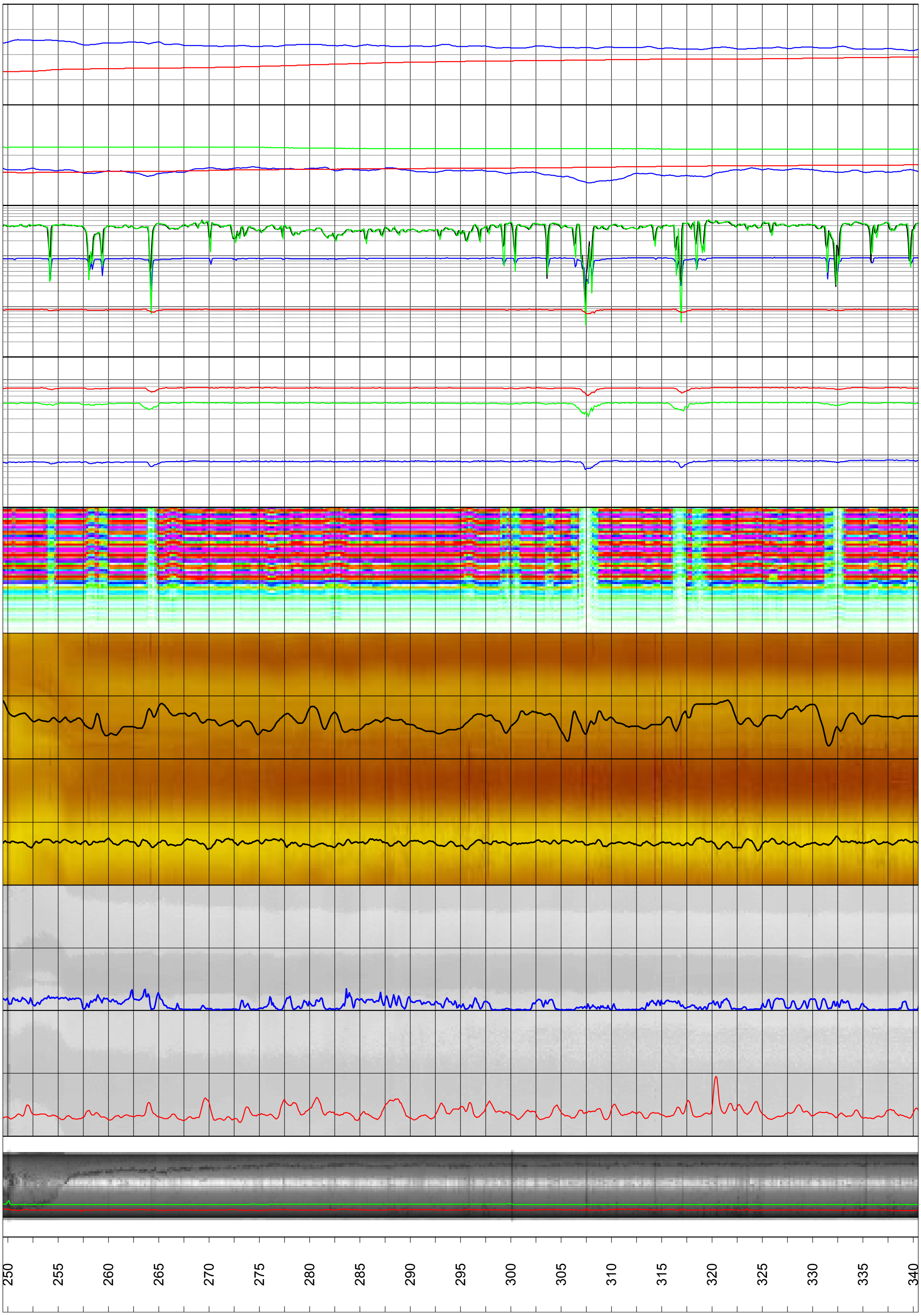
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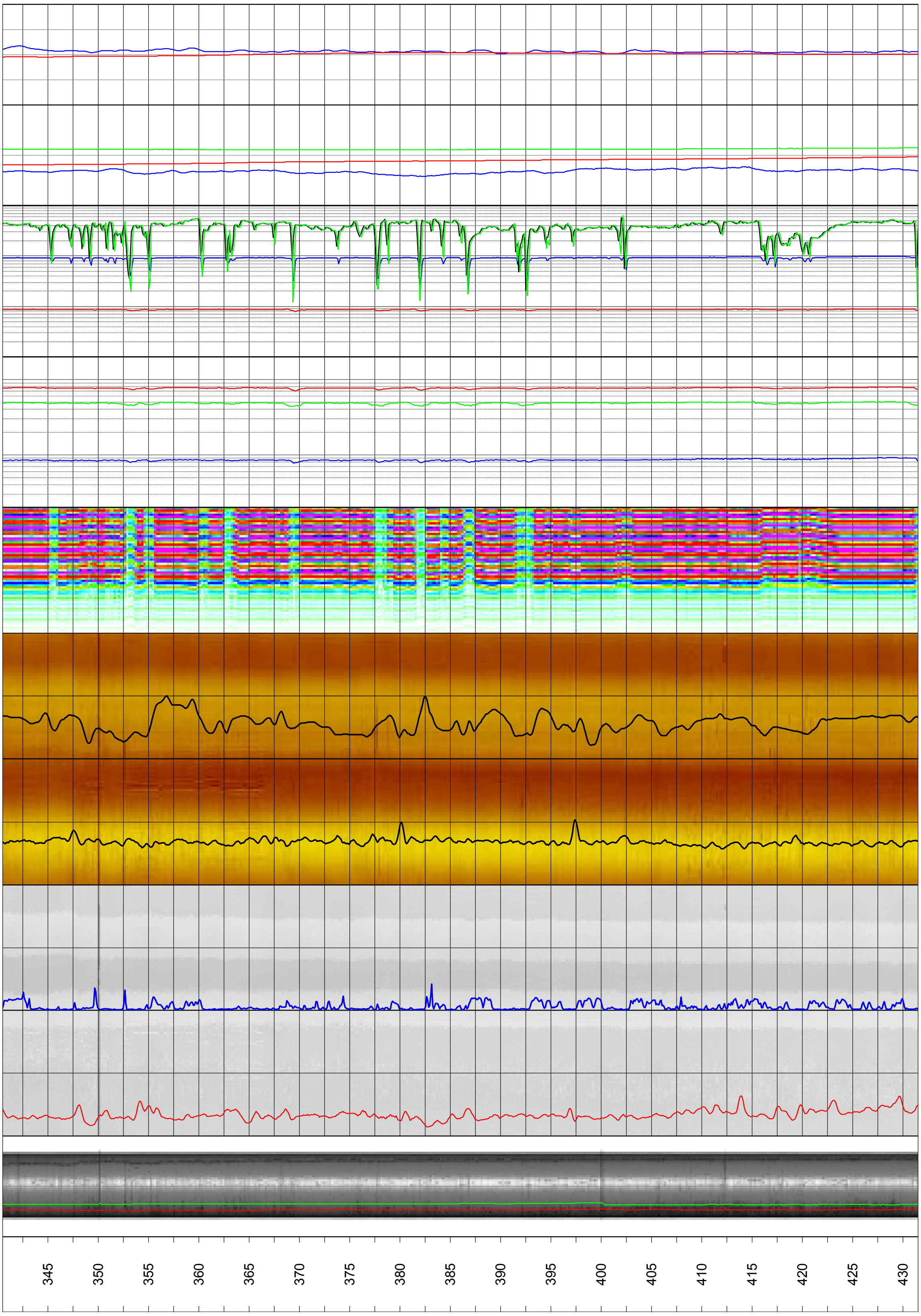
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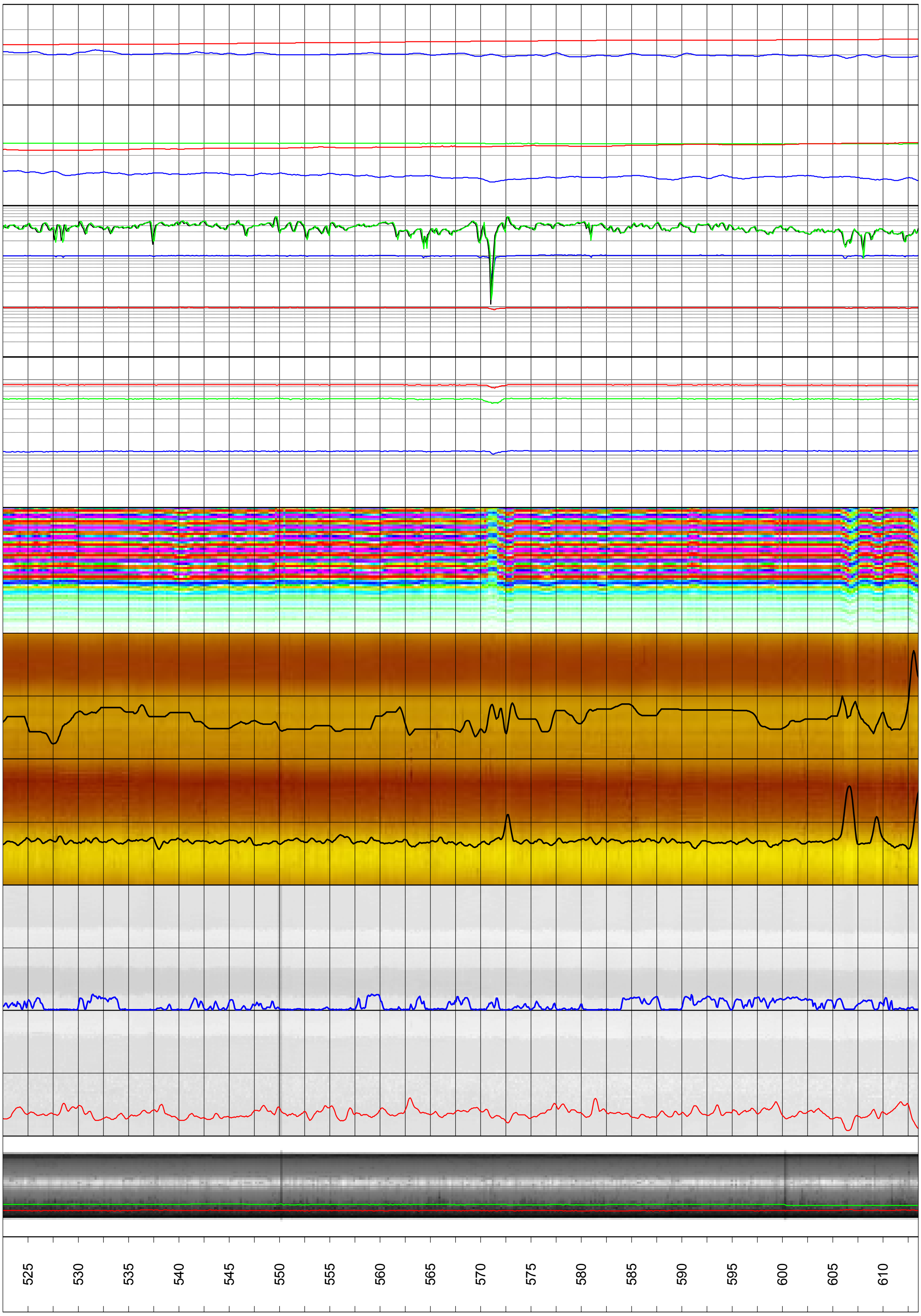
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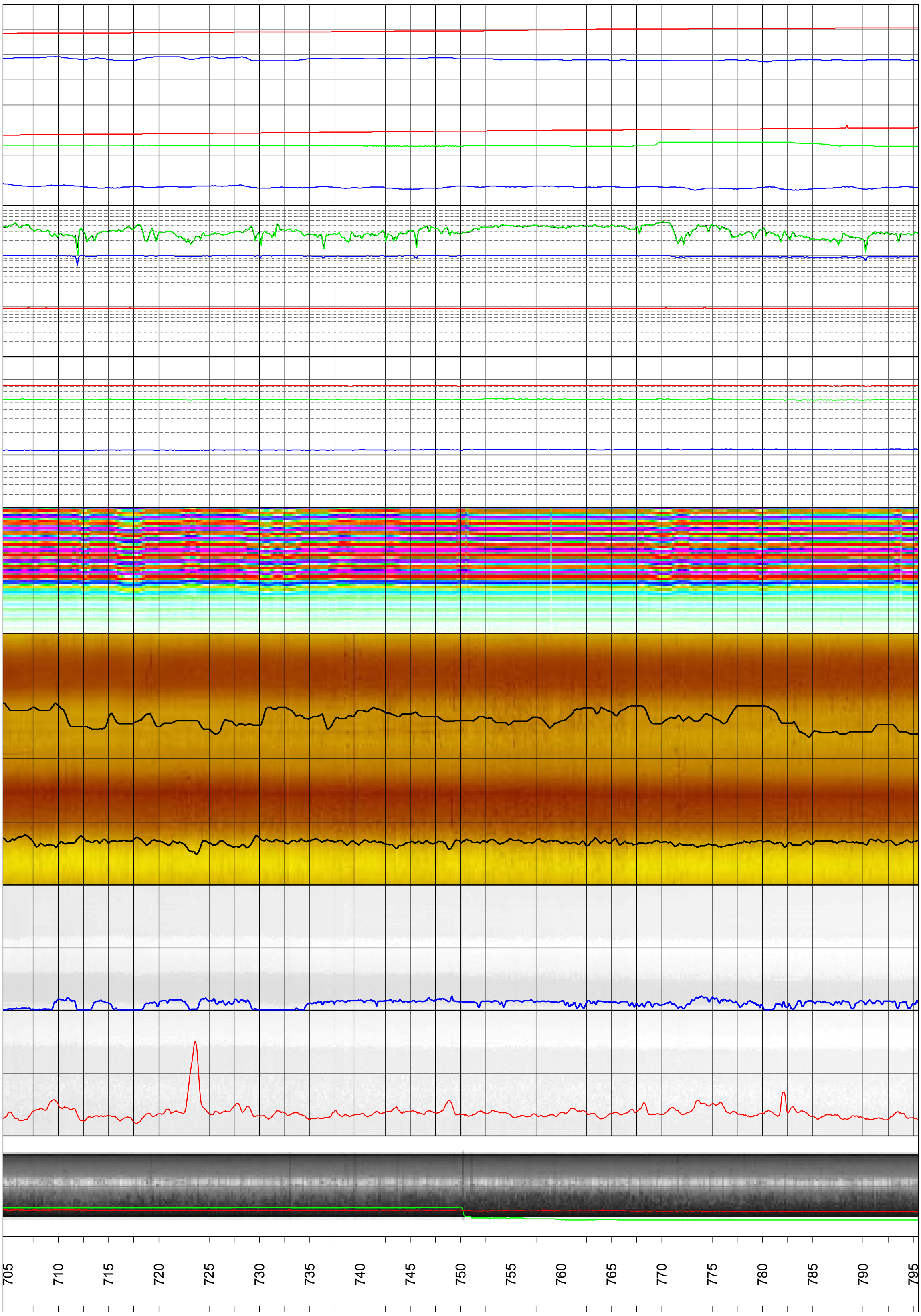
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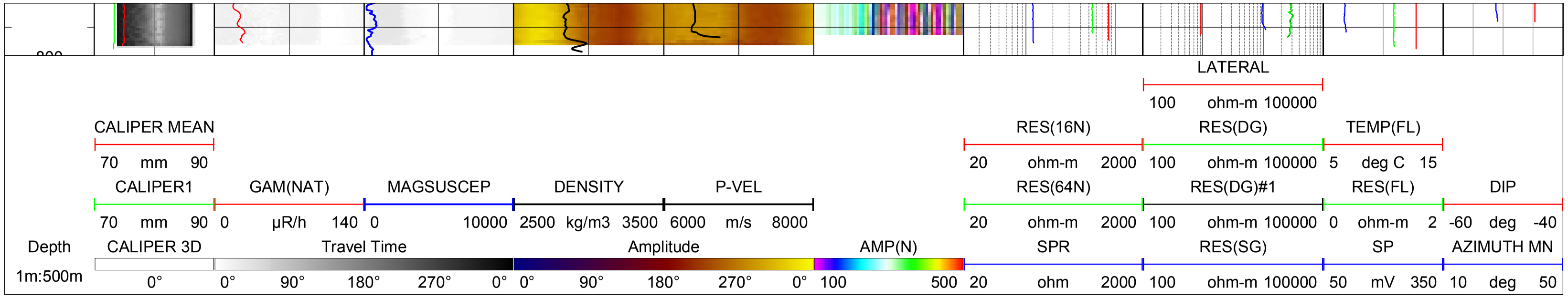

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DENSITY
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P-VEL
6000 m/s 8000
RES(16N)
20 ohm-m 2000
RES(DG)
100 ohm-m 100000
TEMP(FL)
5 deg C 15
RES(64N)
20 ohm-m 2000
RES(DG)#1
100 ohm-m 100000
RES(FL)
0 ohm-m 2
DIP
-60 deg -40
Depth
1m:500m
CALIPER 3D
0°
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Amplitude
0° 90° 180° 270° 0°
AMP(N)
100 500
SPR
20 ohm 2000
RES(SG)
100 ohm-m 100000
SP
50 mV 350
AZIMUTH MN
10 deg 50