P-05-276

Forsmark site investigation

Geophysical borehole logging in the borehole KFM06C

Uffe Torben Nielsen, Peter Skjellerup, Jørgen Ringgaard
RAMBØLL

December 2005

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Keywords: Geophysical borehole logging, Forsmark, AP PF 400-05-068.

Abstract

Geophysical borehole logging has been performed in the borehole KFM06C 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 boreholes.

The logging in KFM06C was recorded from 100 m to 1,000 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 borrhålet KFM06C 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 KFM06C från 100 m till 1 000 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

This document reports the results gained by the geophysical borehole logging in the borehole KFM06C, 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 400-05-068 (SKB internal controlling document). In Table 1-1 the controlling documents for performing this activity are listed.

All measurements were conducted by RAMBØLL during the period August 8 to 10 2005. The borehole was recorded from Top Of Casing (TOC) to the bottom of the borehole. The technical data from the boreholes is given in Table 1-2. The location of the borehole is shown in Figure 1-1 and a technical description is given in Figure 1-2. 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 KFM06C	AP PF 400-05-068	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 boreholes.

Borehole parameter	KFM06C
Coordinates (RT90)	6699740.96 1632437.03
Elevation (RHB70)	4.09 m
Inclination (from horizontal)	–60.12°
Azimuth	26.07°
Length	1,000.43 m
Casing	102 m
Cleaning level	Level 2

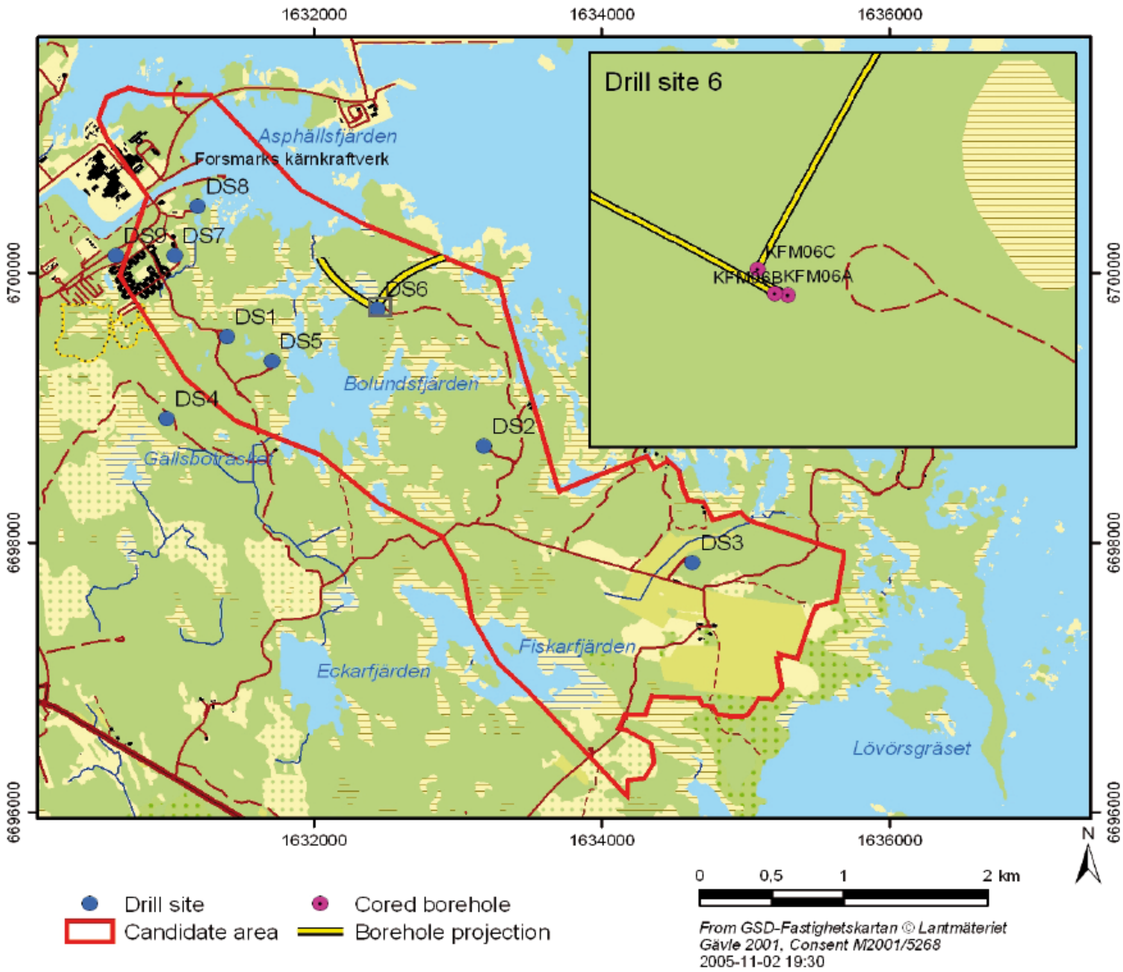
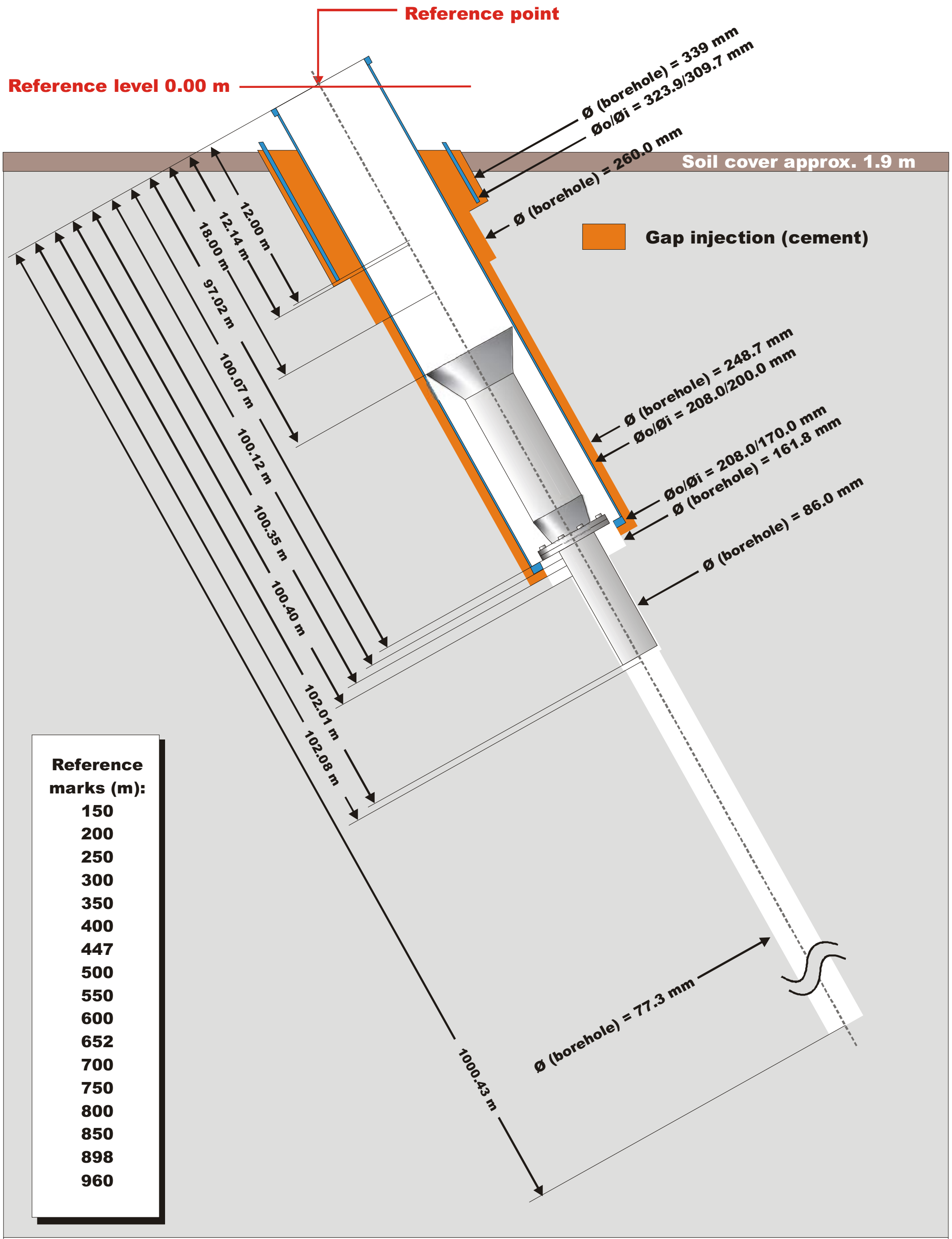


Figure 1-1. *General overview over the Forsmark area with a detailed view of drill site DS6.*

Technical data
Borehole KFM06C



Drilling reference point
Northing: 6699740.96 (m), RT90 2,5 gon V 0:-15
Easting: 1632437.03 (m), RT90 2,5 gon V 0:-15
Elevation: 4.09 (m), RHB 70

Orientation
Bearing (degrees): 26.07°
Inclination (degrees): –60.12°

Borehole
Length: 1,000.43 m

Percussion drilling period
Drilling start date: 2005-03-09
Drilling stop date: 2005-04-13

Core drilling period
Drilling start date: 2005-04-27
Drilling stop date: 2005-06-29

Rev. 2005-08-11

Figure 1-2. *Technical description of borehole KFM06C.*

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 boreholes. Acoustic televiewer was used 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 graphs as a function of borehole length in drawing no 1.1 in Appendix 1.

3 Equipment

The geophysical borehole logging program in KFM06C was performed with 7 multi-tool probes and resulted in a suite of 19 log types, listed in Table 5-1 (Chapter 5). The tools and recorded logs are listed in Table 3-1 below.

Table 3-1. Logging tools and logs recorded.

Tool	Recorded logs	Dimension	Source detector spacing and type	Tool position in borehole
Century 8144 Normal resistivity, fluid temperature and fluid resistivity.	Normal resistivity (16 and 64 inch), single point resistance and natural gamma.	237×5.3 cm		
Century 8622 Magnetic susceptibility.	Magnetic susceptibility, natural gamma.	203×4.1 cm		
Century 9030 Gamma density.	Gamma density, natural gamma, 140 cm focused guard log resistivity, 10 cm 1-arm caliper.	307×5.6 cm	20.3 cm 125 mCi Cs137	Sidewall. Gamma source focused.
Century 9042 Fluid temperatur and fluid resistivity.	Fluid temperature, fluid resistivity and natural gamma.	137×4.1 cm		
Century 9072 3 m focused guard.	3 m focused guard log resistivity and natural gamma.	310×6.4 cm		
Century 9310 Sonic.	Full wave form travel-time providing P and S-wave velocity picking, compensated P-wave travel-time and natural gamma.	283.2×5.1 cm	Near 2 ft. Far 3 ft.	Centralized.
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.

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 August 8 to 10, 2005. All relevant logging events are described in the daily report sheets delivered to SICADA and are traceable by the activity 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 9030 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 9030 tool was 5 m/min, for the 8622 tool 20 m/min and for all other tools 10 m/min.

4.2 Nonconformities

The logging has been performed in accordance with the activity plan AP PF 400-05-068.

5 Results

5.1 Presentation

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

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

Table 5-1. Logs presented in drawing 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
Magnetic susceptibility	MAGSUSCEP	$SI \times 10^{-5}$	8622
Caliper, 1-arm	CALIPER1	mm	9030
Gamma-gamma density	DENSITY	kg/m^3	9030
Focused guard log resistivity, 140 cm	RES(MG)	ohm-m	9030
Natural gamma	GAM(NAT)	μR/h	9030
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
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. 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 constructed 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 all 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.

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 by 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 the 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.
360° orientated acoustic travel time	–
360° orientated acoustic travel time	–

5.4 Borehole KFM06C

In order to obtain an exact depth calibration in borehole KFM06C, 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 match between given depths of the reference marks and the recorded data is obtained. By means of alignment of the observed gamma events in KFM06C, between all log runs, the obtained reference mark correlation is transferred to the other logs.

The complete log suite for borehole KFM06C 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 form the HiRAT in borehole KFM06C.

Reference mark	HiRAT recorded
150.00	147.21
200.00	197.276
250.00	247.37
300.00	297.468
350.00	347.554
400.00	397.649
447.00	444.723
500.00	497.841
550.00	547.921
600.00	597.998
652.00	650.091
700.00	698.161
750.00	748.274
800.00	798.342
850.00	848.44
898.00	896.513
960.00	958.605

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, see 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 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
KFM06C	8144	Down	KFM06C_08-09-05_13-15_8144C_.02_97.95_ 1003.93_ORIG.log	Start Depth: 97.95 m. End Depth: 1,003.93 m
KFM06C	8622	Up	KFM06C_08-09-05_19-33_8622C_.02_92.30_ 1001.57_ORIG.log	Start Depth: 1,001.57 m. End Depth: 92.3 m
KFM06C	9030	Up	KFM06C_08-09-05_16-04_9030CA_.02_91.00_ 1001.87_OR.log	Start Depth: 1,001.87 m. End Depth: 91 m
KFM06C	9042	Down	KFM06C_08-10-05_08-01_9042C_.02_13.97_ 1000.90_ORIG.log	Start Depth: 13.97 m. End Depth: 1,000.9 m
KFM06C	9072	Up	KFM06C_08-10-05_13-15_9072C_.02_95.71_ 1003.56_ORIG.log	Start Depth: 1,003.56 m. End Depth: 95.71 m
KFM06C	9310	Up	KFM06C_08-10-05_15-58_9310C2_.02_98.00_ 1001.89_OR.log	Start Depth: 1,001.89 m. End Depth: 98 m
KFM06C	HiRAT	Up	KFM06C_Hirat_90_up2.HED	Start Depth: 1,000 m. End Depth: 0 m

Table 6-2. Drawing files in WellCad format.

Borehole	Drawing	WellCad file
KFM06C	1.1	KFM06C_Presentation.WCL

Table 6-3. Data files in SICADA format.

Sheet	Comment
KFM06C_CALIPER1_GP040 – Caliper logging.xls	
KFM06C_CALIPER MEAN_GP041 – 3-D caliper.xls	
KFM06C_TEMP(FL)_RES(FL)_GP060 – Fluid temperature and resistivity logging.xls	
KFM06C_DENSITY_GP090 – Density logging.xls	
KFM06C_MAGSUSCEP_GP110 – Magnetic susceptibility logging.xls	
KFM06C_GAM(NAT)_GP120 – Natural gamma logging.xls	
KFM06C_SPR_GP150 – Single point resistance logging.xls	
KFM06C_RES(64N)_GP160 – Resistivity, normal 1.6 m (64 in).xls	
KFM06C_RES(MG)_GP161 – Resistivity, focused 140 cm.xls	
KFM06C_RES(DG)_GP162 – Resistivity, focused 300 cm.xls	
KFM06C_LATERAL_GP163 – Resistivity, lateral 1.6–0.1 m.xls	
KFM06C_RES(16N)_GP164 – Resistivity, normal 0.4 m (16 in).xls	
KFM06C_P-VEL_GP175 – Fullwave sonic.xls	

Appendix 1

Borehole KFM06C, drawing no 1.1, borehole logs

Borehole No. KFM06C

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

Northing: 6699740.96 Easting: 1632437.03 Elevation: 4.09

Diameter:	77.3 mm
Reaming Diameter:	
Outer Casing:	
Inner Casing:	
Borehole Length:	1000.43 m
Cone:	
Inclination at ground surface:	-60.12 deg
Azimuth:	26.07 deg
Comments:	

Borehole logging programme

Name	Description	Tool	Unit
CALIPER1	Caliper, 1-arm	9030	mm
DENSITY	Gamma-gamma density	9030	kg/m³
RES(MG)	Focused guard log resistivity, 140cm	9030	ohm-m
GAM(NAT)	Natural gamma	9030	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

Rev.	Date	Drawn by	Control	Approved
1	2005-09-30	UTN	JRI	UTN

Job	Scale
0547310A	1:500

RAMBØLL

Rambøll. Bredevej 2, DK-2830 Virum
Phone + 45 45 98 60 00, Fax + 45 45 98 67 00

SKB geophysical borehole logging
Borehole KFM06C

Filename:
KFM06C_presentation.wcl

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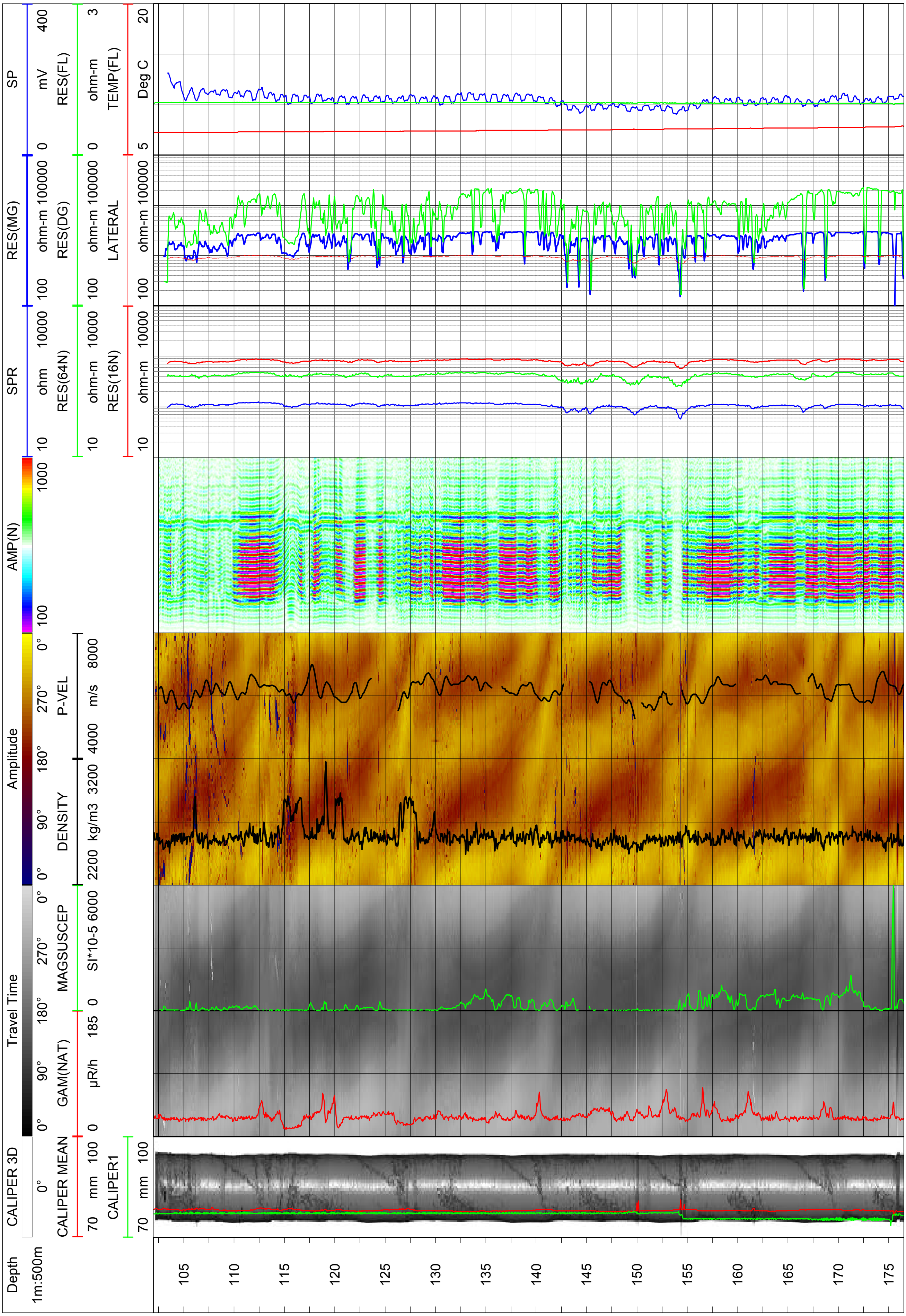
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P-VEL
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MAGSUSCEP
0 SI*10-5 6000
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CALIPER MEAN
70 mm 100
CALIPER1
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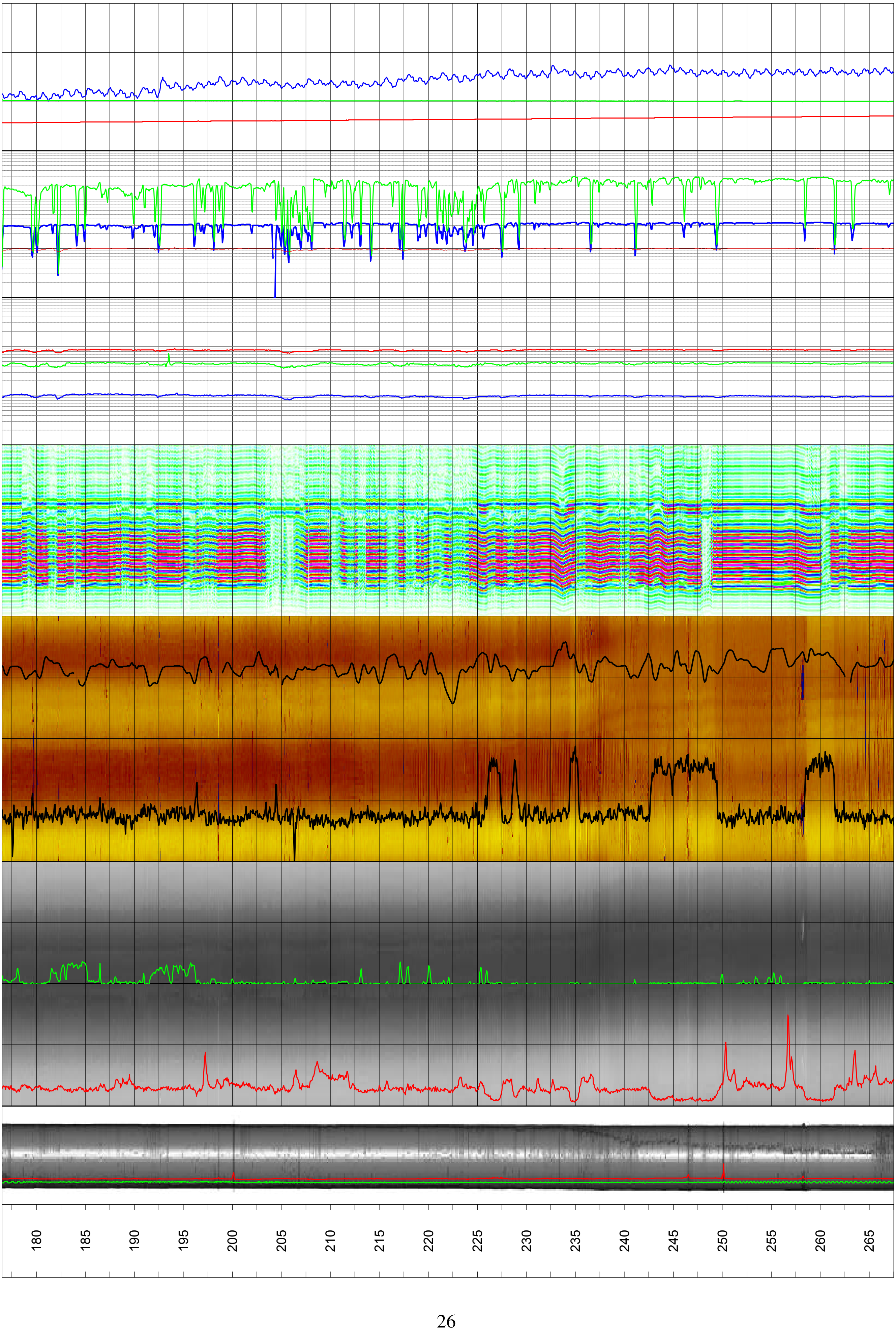
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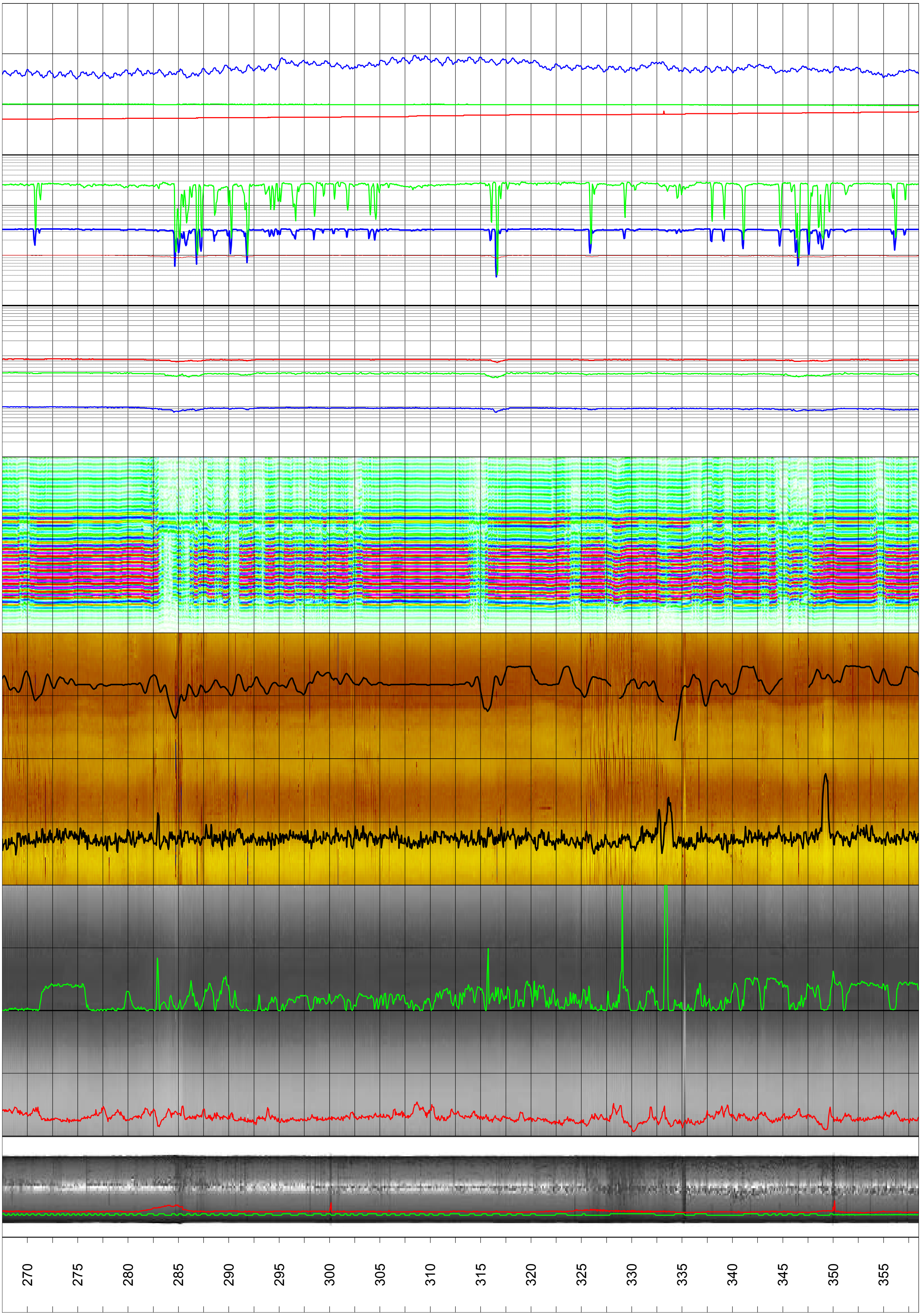
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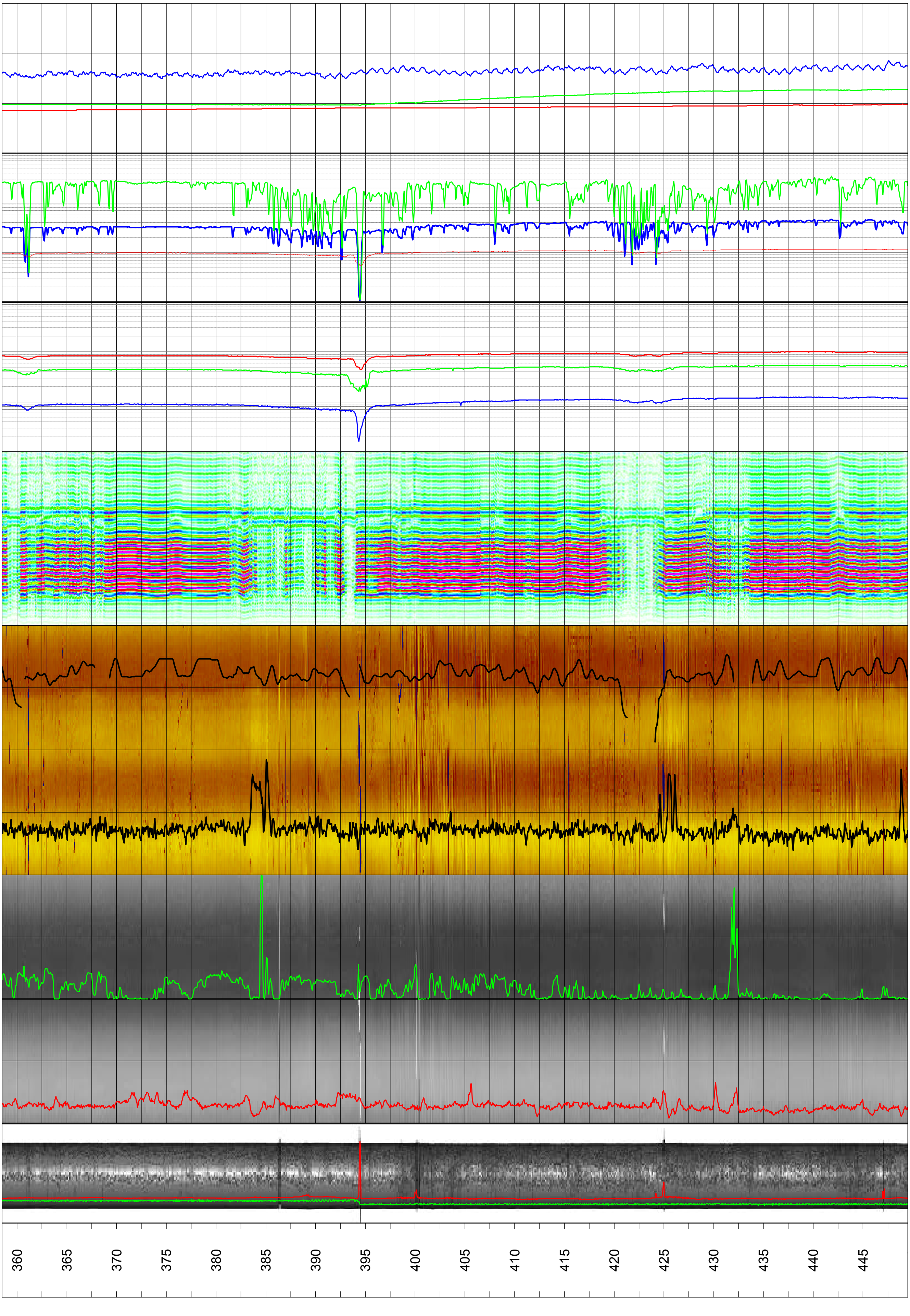
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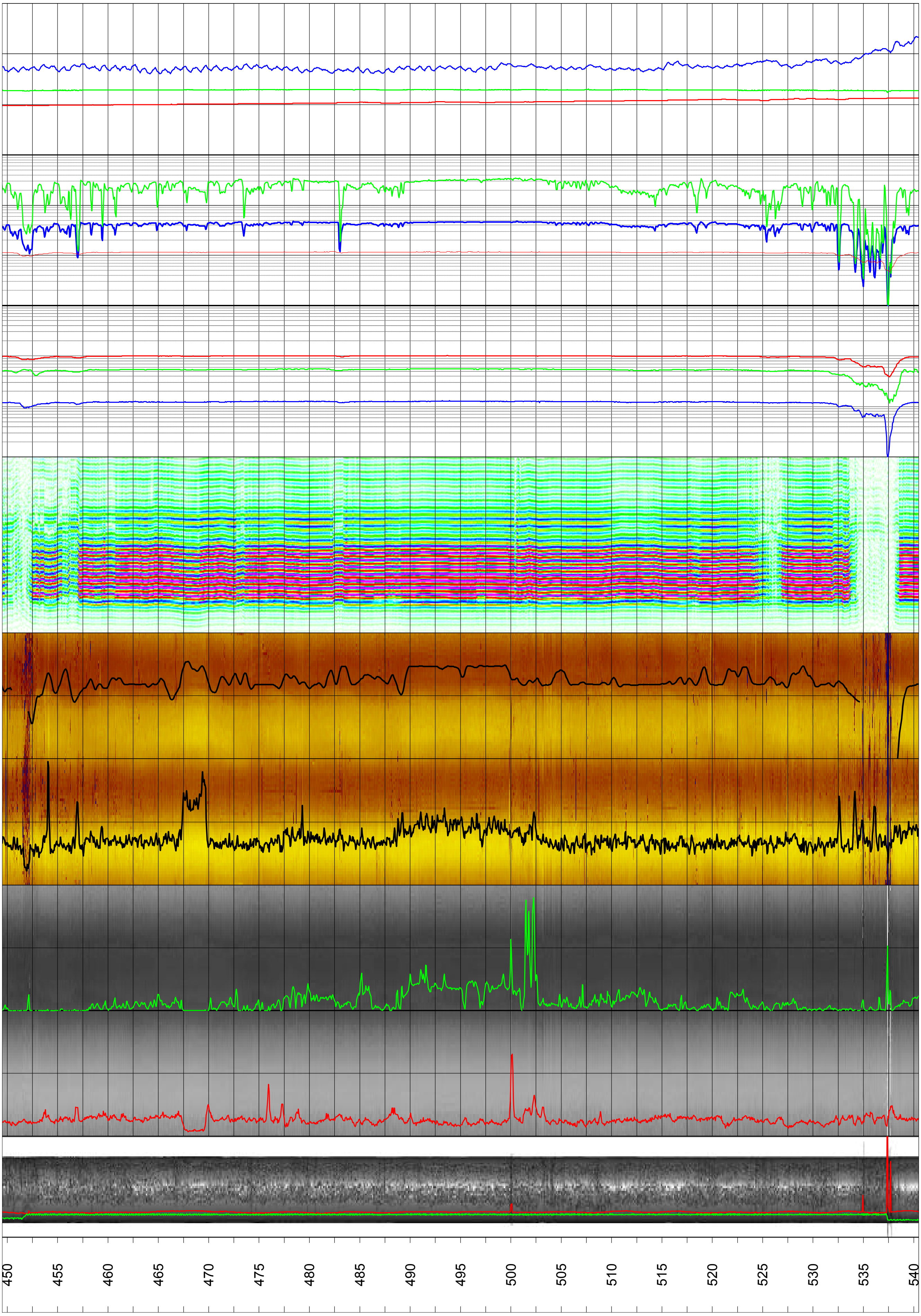
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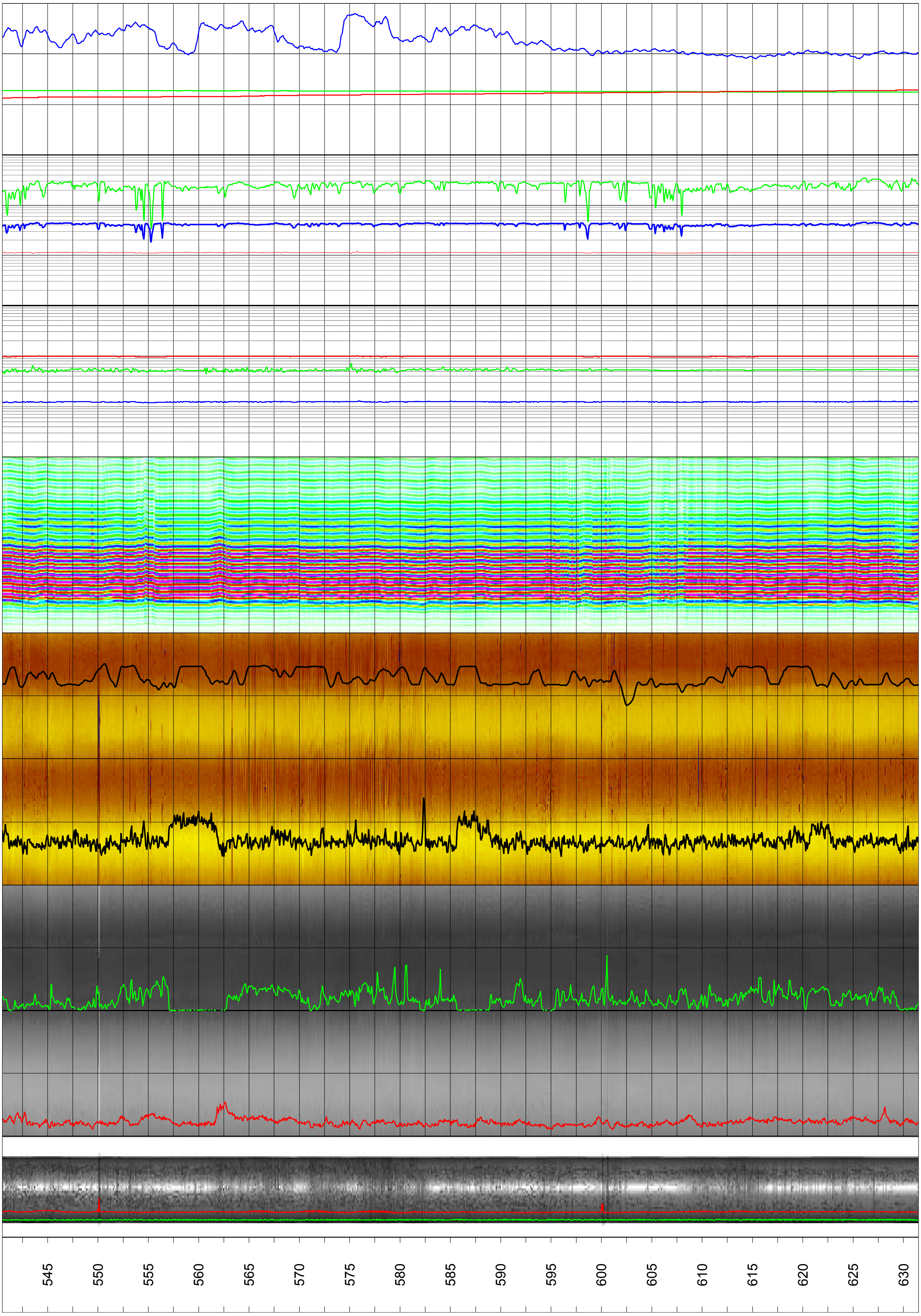
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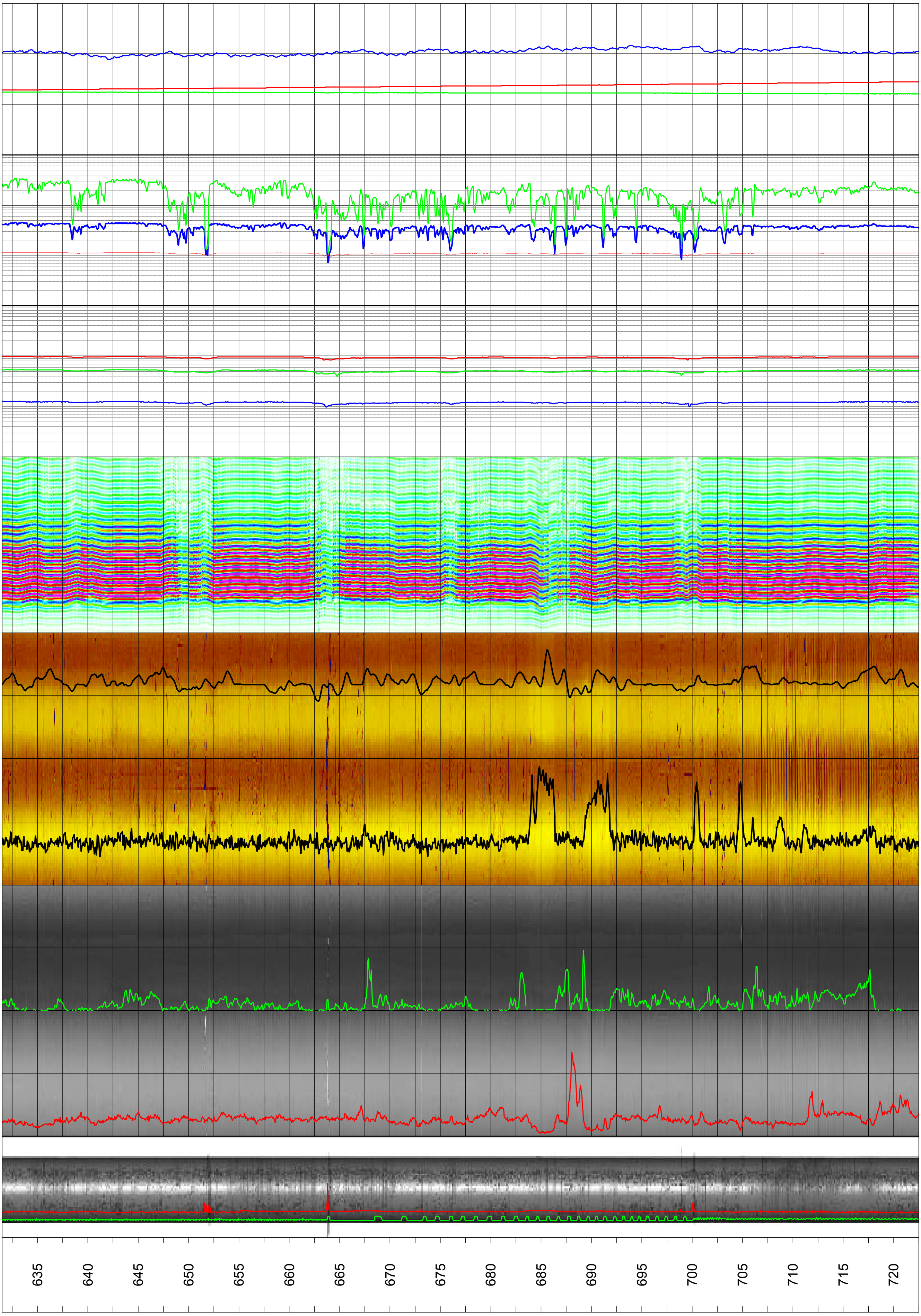
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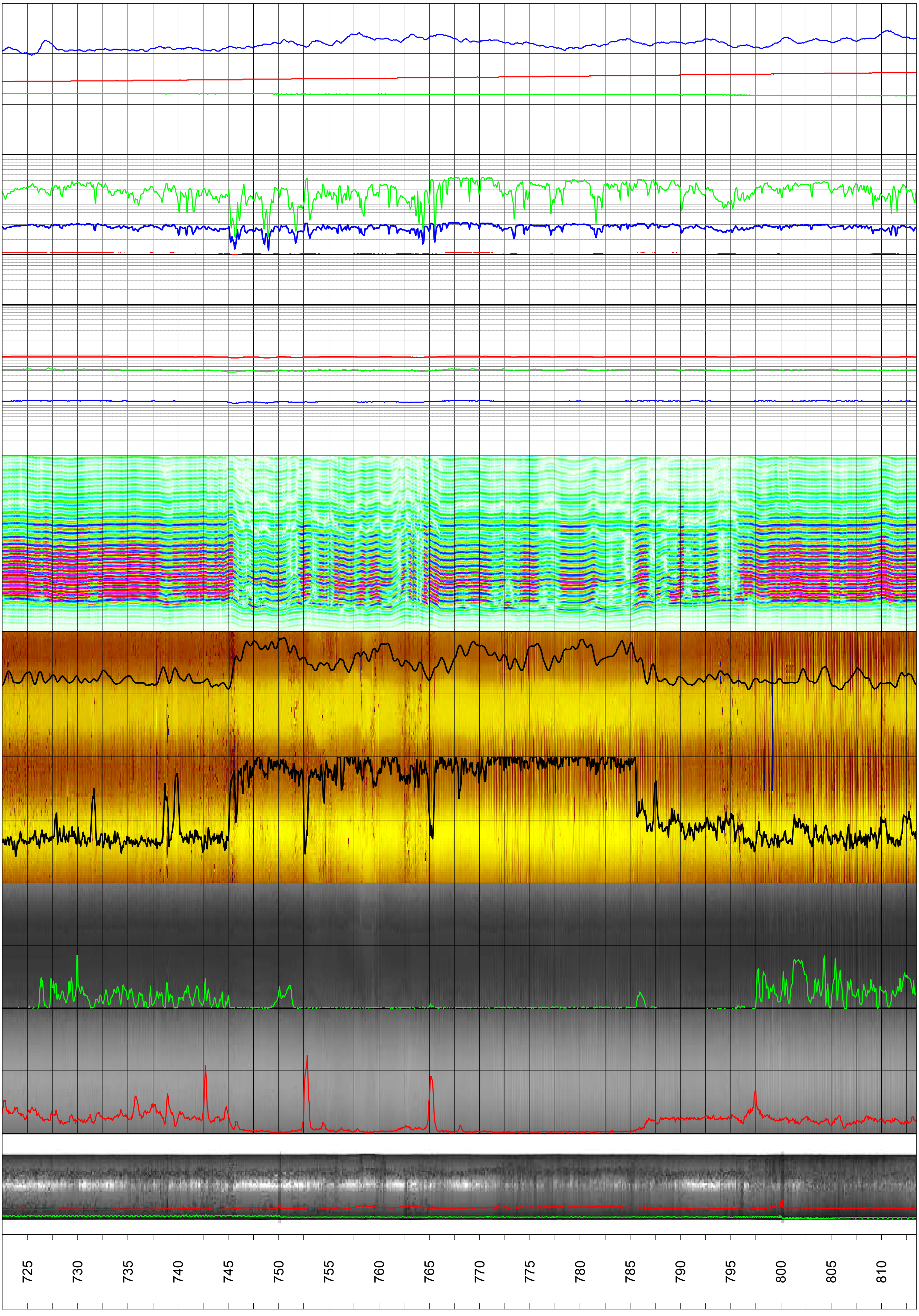
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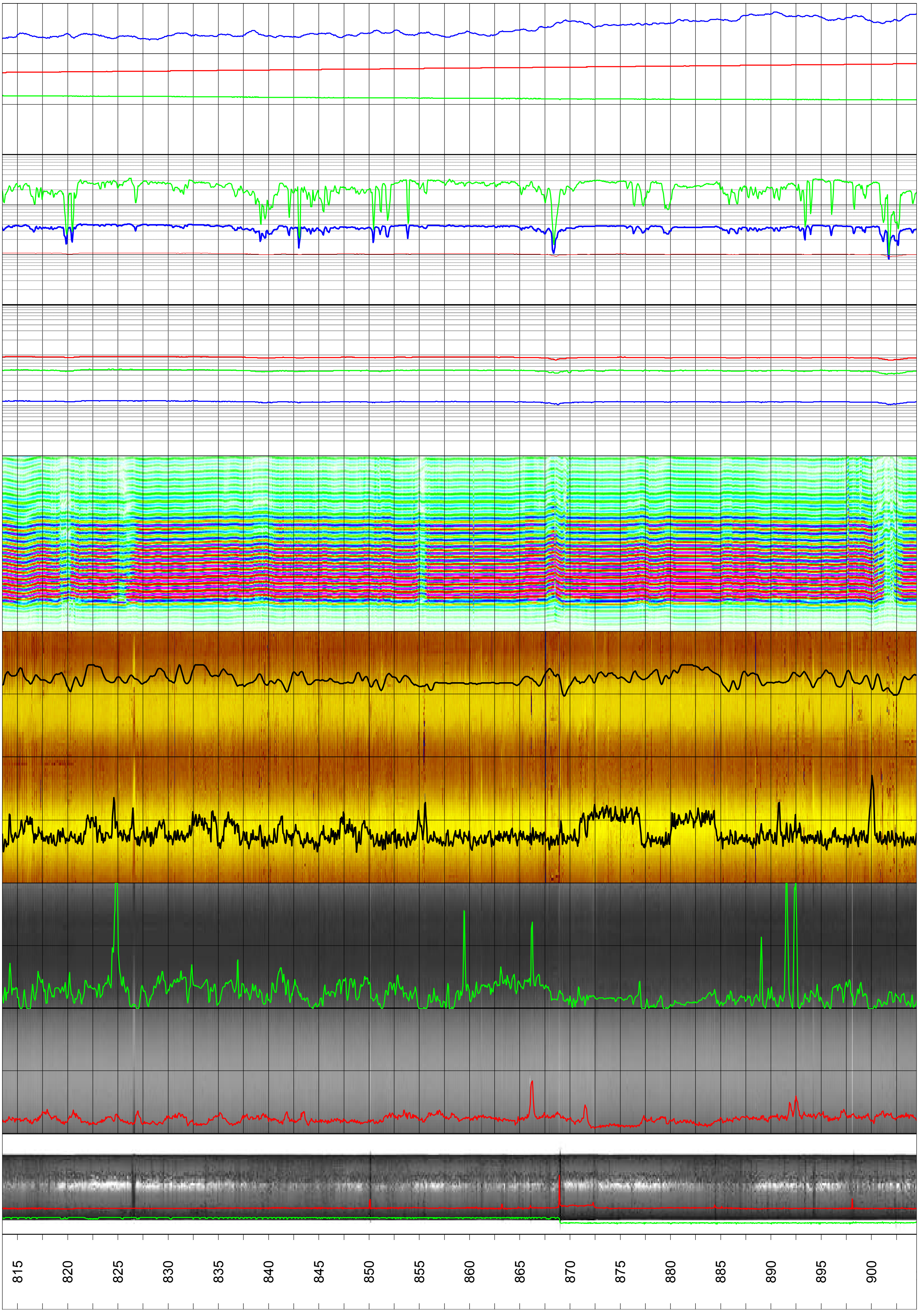
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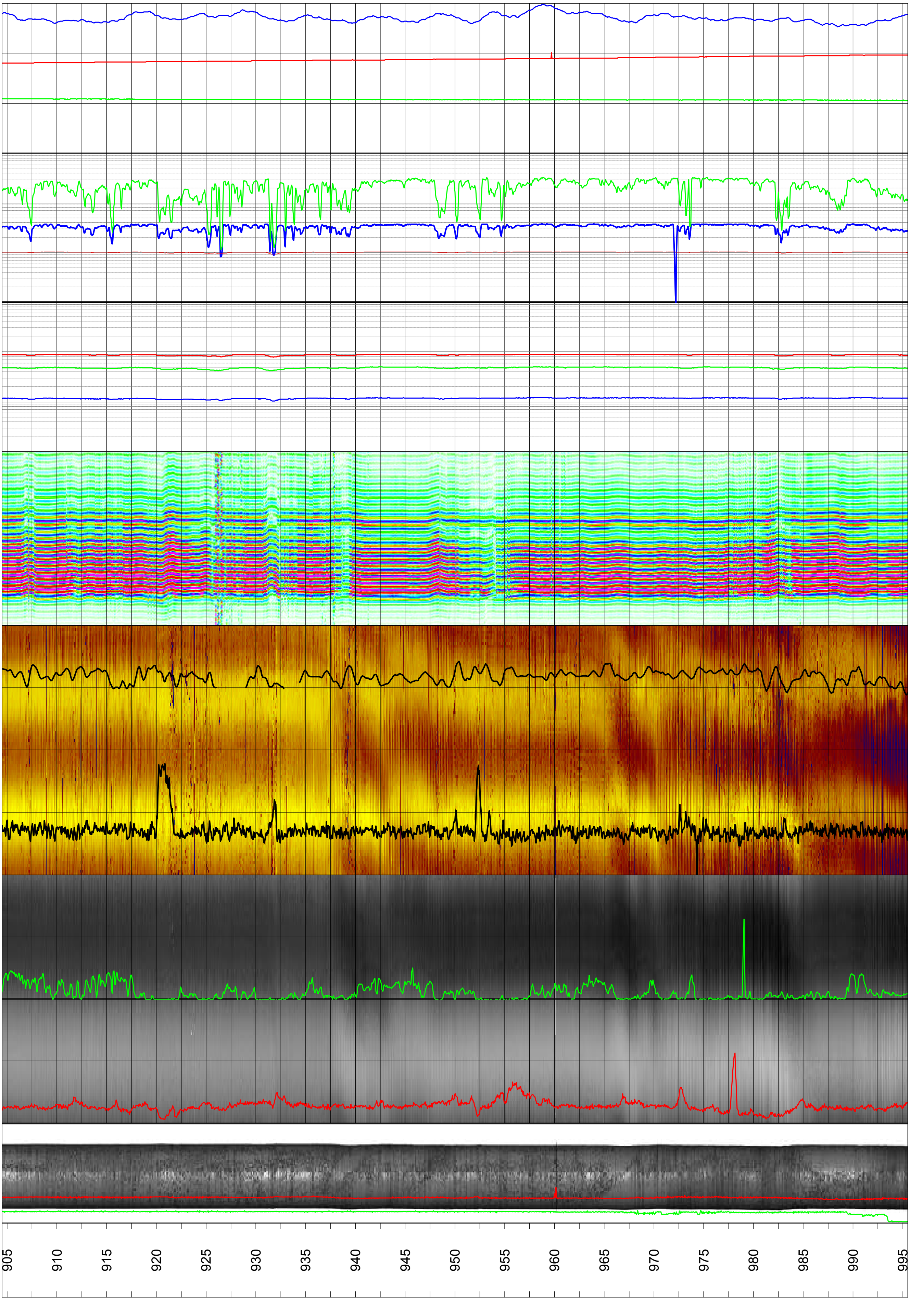
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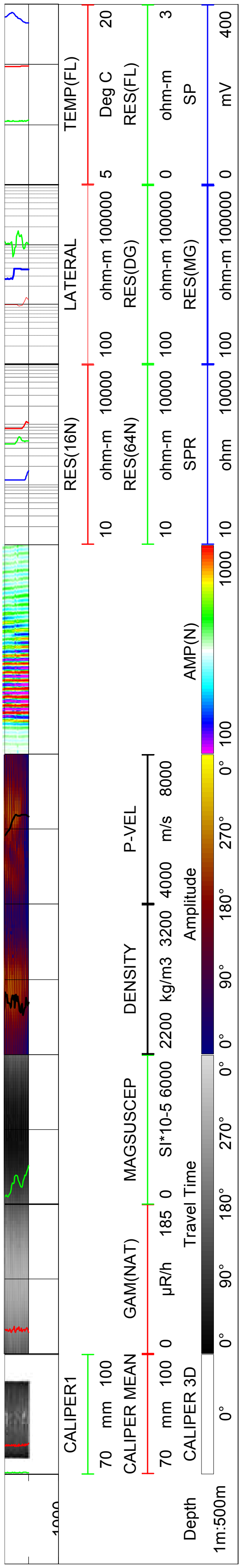
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70 mm 100
CALIPER MEAN
70 mm 100
CALIPER 3D
0°
GAM(NAT)
0 µR/h 185
MAGSUSCEP
0 SI*10-5 6000
Travel Time
0° 90° 180° 270° 0°
DENSITY
2200 kg/m3 3200
P-VEL
4000 m/s 8000
Amplitude
0° 90° 180° 270° 0°
AMP(N)
100 1000
RES(16N)
10 ohm-m 10000
RES(64N)
10 ohm-m 10000
SPR
10 ohm 10000
LATERAL
100 ohm-m 100000
RES(DG)
100 ohm-m 100000
RES(MG)
100 ohm-m 100000
TEMP(FL)
5 Deg C 20
RES(FL)
0 ohm-m 3
SP
0 mV 400