Intended for
Malmberg Borrning AB

Document type
Datarapport

Date
August 2016

MALMBERG BORRNING AB

FLOWLOGGING IN BOREHOLE PB0901 IN YNGSJÖ

RAMBØLL ENVIRON

MALMBERG BORRNING AB
FLOWLOGGING IN BOREHOLE PB0901 IN YNGSJÖ

Revision	**0**
Date	**25/08/2016**
Made by	**GA**
Checked by	**UTN**
Approved by	**UTN**
Description	**Target: Identification of presence and inflow zones with saline water. Work: Geophysical borehole logging. Reported logs: Flow/temperature/salinity measured before-, during- and after pumping, natural gamma, caliper, focused formation resistivity and electromagnetic induction.**

Ref	Kristianstad Kommun_Malmberg_Geophysical Logging In Vantamansvägen PB0901 In Yngsjö_1100003017-034.Docx
Document ID	1100003017-740111945-10
Version	0

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark
T +45 5161 1000
F +45 5161 1001
www.ramboll.com

CONTENT

APPENDIX

PB0901_20160823_Geophysical-boreholelog_v0 1-100.pdf
PB0901_20160823_Geophysical-boreholelog_v0 1-1000.pdf
PB0901_20160823_Geophysical-boreholelog_v0.las
PB0901_20160823_Geophysical-boreholelog_v0.wcl

1. INTRODUCTION

Ramboll has performed geophysical borehole logging in borehole no PB0901 in Yngsjö for Malmberg Borrning AB, Sweden. Logging is performed the 23th august 2016. The borehole is located in a forest at Vantamansvägen close to a bicycle lane. The distance to the Baltic Sea is app. 600m.

The borehole was drilled in 2009 to 178m with open section of formation 71-178m b.GL. The borehole is intended to be a new water supply well. But the water quality is not yet satisfying due to a content of salinity. The target for the borehole logging is to support the ongoing hydrogeological modelling on the problem, and then also to support a decision to solve the problem if possible.

Logging programme:

- Natural gammaray
- Caliperlog
- Flowlog/temperature/salinity before pumping (Impeller calibration and baseflow)
- Flowlog/temperature/salinity during pumping (Flow)
- Flowlog/temperature/salinity after pumping (Ekstra monitoring of temp. & salin.)
- Focused formation resistivity
- Electromagnetic induction

Malmberg Borrning AB has assisted with waterpumping during the flowlog.

This report describes:

- Completed work
- Interpretation of flowlogs
- Data presentation

2. COMPLETED WORK

2.1 Equipment and preparation

The logging data are recorded with GeoVista logging equipment.

The logging equipment is cleaned with high pressure warm water before logging in water supply boreholes as shown on Figure 2-1.

Figure 2-1: High pressure cleaning of logging tools.

2.2 Logging depth

All depth data has reference to the top of steel lid, located app. 0.50m above ground level.

2.3 Caliper

The 3-arm caliper is recorded uphole with logspeed 12m/min. The borehole bottom was soft, and the 3-arm caliper was only able to open the caliper arms from 174.95m only.

2.4 Gamma

The presented natural gamma curve is a mean curve from 8 logruns with app. 12m/min. The curve is calculated after the standard depth QC of the logging depths.

2.5 Flow

Flow and basisflow are recorded with logspeed 12m/min.

Calibration statistics:
Downhole: 10 cal. points, linear regression coefficient R^2 = 0.9990
Uphole: 9 cal. points, linear regression coefficient R^2 = 0.9992

The impeller tends to stop randomly in the zone 105-140m. This is a typical situation in boreholes with precipitations present, particularly if the borehole is inclined also. The top of borehole PB0901 was clearly inclined at the upper visible part down to 5.33m.
The problem was flushed away by shaking the tool up and down.
The water from the pump was black as shown on the picture on the frontpage of this report, and this is a strong indicator for precipitated manganese downhole.

The sections of data where the impeller was disturbed of precipitates was sufficient narrow to be edited by interpolation.

2.6 Temperature- and salinity

The tool was stacked with the flowtool and recorded under the same circumstances as the flow described above. Typical logspeed was 12m/min.

2.7 Electromagnetic induction

The tool is run uphole with 12m/min uphole.

2.8 Focused formation resistivity

The tool is run uphole with 12m/min uphole.

3. RESULTS

3.1 Caliperlog

Cavities can be observed in the glauconite formations in 123-131m and 166.3-174.8m. The rest of the borehole wall is fairly smooth.

3.2 Flow

The manually interpreted flowzones can be found on the logsheets, and the same data are presented below in Table 3-1 also. The inflow zones are interpreted on a curve for the yield, calculated from the FLOW_U and CAL3 curve and scaled to 100% in the steel casing.

Interpretated flowzones		
Top Depth	Bottom Depth	Inflow in pct. of 30m^3/t
m	m	%
54	84	0
84	94	5
94	105	0
105	110	11
110	113.8	12
113.8	114.5	12
114.5	119.5	0
119.5	120	6
120	127	0
127	133	40
133	140	5
140	149	2
149	150	7
150	172	0

Table 3-1: Interpretated inflow zones

3.3 Temperature and salinity

3.3.1 Generally

The measured temperature- and salinity logs corresponds to a limited time of pumping only. Even a very small vertical flux of water over a longer time can have an effect on the water quality during the relative short time of pumping. This borehole is not in regularly use, and some of the water will be pumped back and will not represent the true formation water.

The salinity seems to be complex in this borehole, and modelling of the conditions in the borehole should be considered with respect to the 3D situation. I.e. the borehole is the meeting point for different flowpaths, and there is a possibility for inflow of several kind of water at the same depths resulting in a measured average value.

Another issue is the conditions in the surroundings. Season fluctuations can be present, and daily intermittent water abstractions can give daily fluctuations. This borehole logging is only valid for the conditions during the daytime of the 23th of august 2016.

3.3.2 Conditions in the steel casing

The salinity was about 1600 µS/cm only in the steel casing before the pumping. It increased to 2400 µS/cm during the pumping and didn't tend to decrease after the pumping. The 1600µS/cm value represents the water quality at the last time someone has pumped from the borehole. This conclusion presumes that no other process is present around the casing. I.e. no chemical reactions with the steel casing, precipitations, and no leakages through steel junction, leakage on the other side of the casing and no rainwater dropping down from above.

3.3.3 From bottom casing to 105m

A halocline, and minor thermocline, is present right below the bottom of the casing. The salinity values below the halocline seems to be approximately the same constant value 2400 µS/cm both before-, under and after the pumping. This value is constant at least down to 105m where the induction and focused formation resistivity indicate slightly higher salinity of formation water. (Since the gamma curve doesn't show any changes at the 105m depth.) This depth is also the top of a flow zone (see the flowlog).

3.3.4 Zones with saline water 105-140m.

This zone can be divided in three major sub zones when compared with the induction and formation resistivity logs.
105-115m: Upper zone - Borehole fluid salinity between 2300 and 2700 µS/cm.
115-127m: Middle zone - Borehole salinity close to 2400 µS/cm.
127-140m: Lower zone - Borehole fluid salinity up to 3000 µS/cm.

The borehole fluid salinity in the middle zone has the same stable value before, during and after pumping, while the upper and lower zone seems to have a much more dynamic response.

The dynamics could be effects from the issues mentioned in chapter "3.3.1 Generally" above. And further conclusions should only be made on additional tests. There might be a chance for increased, or decreased, salinity during further pumping.

A study (optical televiewer) on the precipitates, and level specific water samples, might also be the key to understand the dynamics of zone 105-140m.

3.3.5 Bottom section 140m-175(178)m

The salinity from 140m and down to the borehole bottom seems to be relative fresh with values about 525 µS/cm.

The shape of the salinity curve before pumping is a known shape for a water column with unstable density distribution. I.e. high density water at top (warm and saline) and low density water at bottom (cold and fresh). Small density plumes will try to stabilize the water column resulting in higher salinity at the bottom and a lower salinity at the top.
This salinity shape disappears during the pumping, and the salinity during pumping discover at least one extra inflow zone in 151.5m. This inflow zone is very weak since it is impossible to detect directly from the flowlog. The flowlog response is even negative at this depth, and that indicate small inflow overlaid by the effect from a twistflow.

Another minor inflow is also present somewhere close to 165m where the salinity before and during pumping is meeting.

The question is how the freshwater salinity can be maintained at the bottom of the borehole. The borehole is not pumped regularly, and the density plumes interacting with the saline water in the zone above 140m should have done the EC25_F curve constantly saline with app. 3000 µS/cm from 140m and down to the bottom. The answer is that a small vertical uphole flow must be present from the bottom section of the borehole and up to at least 140m, and this flow is strong enough to maintain the freshwater in the bottom section, but not strong enough to eliminate density plumes totally. In other words: *There is an uphole hydraulic gradient at the bottom section with freshwater*.

The dynamics of the borehole fluid can be studied in Table 3-2 and Figure 3-1. Table 3-2 show the logging timestamps together with the lognames, and the corresponding logs in Figure 3-1 shows a more individually presentation of the salinity logs. The uphole logs are also presented together in the right part of the pane with the purpose of illustrating the salinity response after the pump is stopped. (There is allways a lagtime in the temperature and conductivity sensor and this affect the data. This give a difference between downhole and uphole logging. So dotted curves is the special symbol for uphole logging.)

Notice the green and black curve after pumping in 135m in the right column on Figure 3-1. It doesn’t turn back toward the blue curve as expected.
Notice also the sudden increase in salinity 120m right after the pumping (green and black curves) in the right column on Figure 3-1: Curves for salinity.

Timestamp (hhmm)	Curve name	Signature	Color
1037	EC25_F a-dn	Full	Blue
1052	EC25_F a-up	Dotted	Blue
1119	EC25_F b-dn	Full	Blue
1133	EC25_F b-up	Dotted	Blue
1229	EC25_U c-dn	Full	Red
1240	EC25_U c-up	Dotted	Red
1252	EC25_U d-dn	Full	Red
1303	EC25_U d-up	Dotted	Red
1336	EC25_E e-dn	Full	Black
1351	EC25_E e-up	Dotted	Black
1404	EC25_E f-dn	Full	Green
1419	EC25_E f-up	Dotted	Green

Table 3-2: Timestamp and curve names

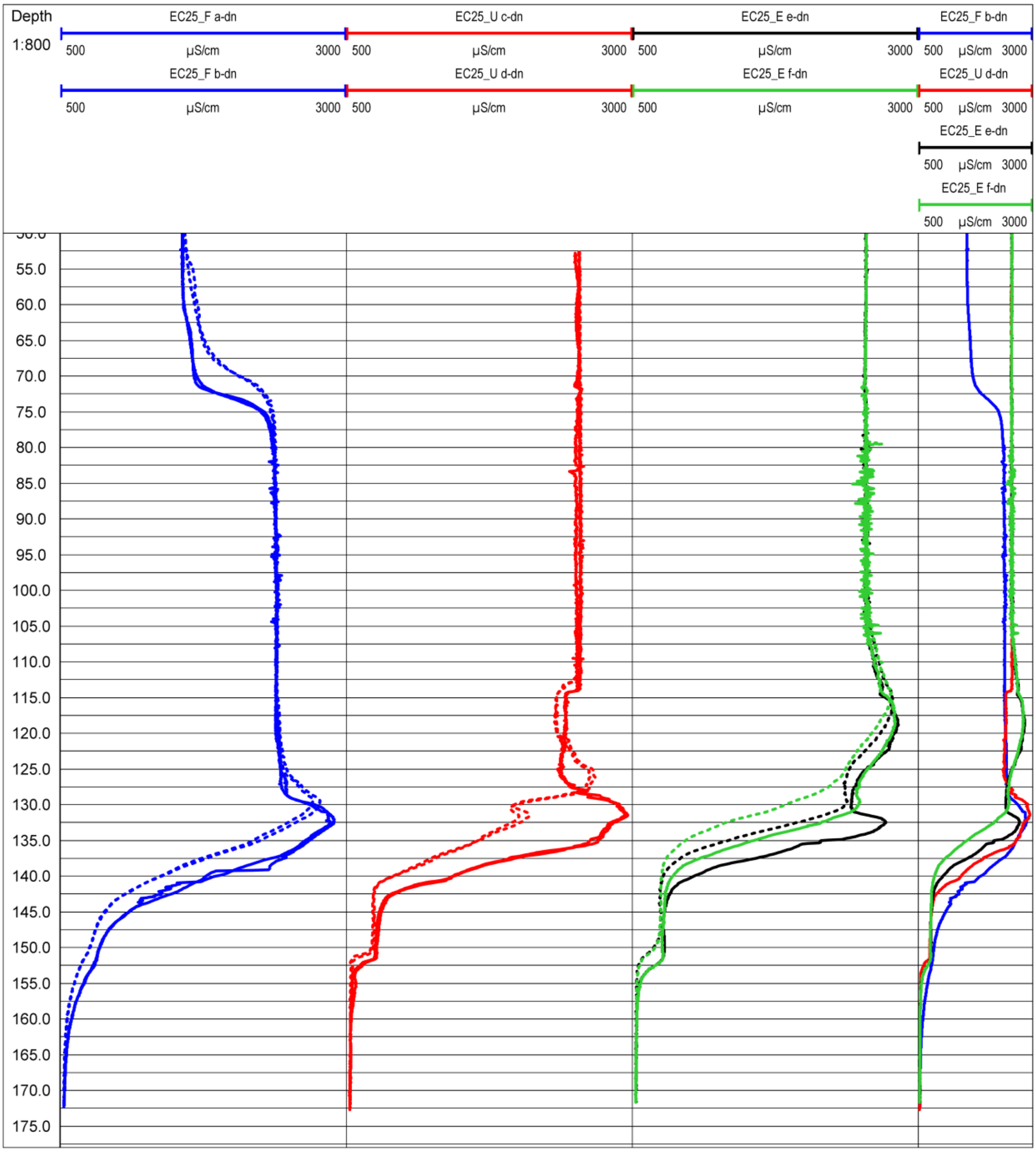


Figure 3-1: Curves for salinity

3.4 Electromagnetic induction

A zone with high induction values is present from 129.5 to 143m with values up to 43 mS/m. This zone covers the upper part of a chalkstone formation. The natural gamma for this part of the chalkstone is low and then with a low content of potassium/clay. So the high induction values are expected to be due to saline water in the formation. The upper boundary for the zone seems to be a layer of solid glauconite.

Another zone with higher induction values is present from 106m to 115m, although the induction value is up to 22 mS/m only.

3.5 Focused formation resistivity

A zone with low formation resistivity is present from 129.5 to 143m corresponding to the results from the induction log. The bottom at 143m seems to be more sharp detected compared with the induction log, and it seems to be correlated to the bottom of af very small peak on the natural gamma log. So this bottom boundary could be a thin layer of clay or marl indicated by the natural gamma.

Another zone with low formation resistivity is present from 106m to 115m although this zone is more easy significant on the induction log.

3.6 Presentation of data

All depth data is measured with reference to top of steel casing.

A graphic presentation of the recorded logging data are shown on the logsheet in appendiz 1: Vantmansvägen PB0901
A scale 1:1000 can be obtained if printed on A3 paper size.

A file with ASCII data (*.LAS) for each logsession is delivered together with this report.

Lognames are described in the logsheet header, and a more detailed description can be found in Tabel 3-3.

Log names	Description
NGAM	Natural gamma ray. The natural gamma ray depends on the actual geology and can be measured through steel and plastic. Typically corresponding to the content of potassium. Clay has a high NGAM due to high potassium content, while sand and chalk has low NGAM values. Natural gamma is valuable for lithological interpretation, and also for QC of logging depth (since a gamma sensor is present in all Rambøll logging tools).
FLOW_F, FLOW_U, FLOW_E	FLOW_F: Flowlog before pumping (Baseflow). FLOW_U: Logrun during pumping (or injection). FLOW_E: Logrun after pumping. The raw data from the impeller flowtool is recorded as spinnings pr minuts only. The result depends on the size and shape of the actual borehole, so the tool is calibrated with different logspeeds in the borehole casing when the waterflow still is zero. I.e. before and/or after the pumping. The impeller is constructed with a very small amount of friction forces only, and the effect from any remaining friction is reduced by the dynamic logging method. I.e. by running the tool continuously with a logspeed though the borehole. This method ensures detailed records with samplings for every 1cm of borehole depth, and it is also timesaving. The logging speed is also recorded to ensure proper compensation for the actual logging speed. The impeller can easily be disturbed from artifacts like precipitates, minor rockfalls, lost pieces of tape and similar, and that is why the flowlogs is repeated to ensure correct quality of data values. The flow data is recorded with both downhole and uphole logruns to ensure proper compensation for piston effect. A

Log names	Description
	caliper log is normally recorded also to ensure proper calculation of the resulting flow expressed in m^3/t, l/s etc. The pump yield is normally recorded also, and this value is compared with the calculated yield in the casing below the pumpe. It should normally match with a factor of about 1.4. The water speed from the logging tool is recorded by a centered tool, and then at the point with maximum water speed in the cross section area of the borehole. So the calculated yield shall allways be higher than the measured pump yield. The presented yield log in (m3/t, l/min etc.) is scaled to true yield matching the measured pumping yield. The processed water velocity (in m/sec) is signed. I.e. with negative values if the water is running toward the borehole bottom. Data is normally stacked to improve any noise level. However, "noise" from small jetstreams from the borehole wall will not be eliminated. It will typically appear at some fractures where the fracture shape and the inflow path create circular water velocity along the borehole wall. It will die out again downstream.
PAYZ	"Payzone". Interpretated inflow zones. Every zone is marked with top depth(m b.ref.point), relative inflow(pct) and top depth(m b.ref.point). The inflow distribution is relative to the measured yield above top of filter.
CAL3	3-armed mecanical caliper. Diameter destribution of the borehole.
TEMP_F, TEMP_U, TEMP_E EC25_F, EC25_U, EC25_E	TEMP: Temperature of the water or drillmud. EC25: Salinity or fluid conductivity at 25°C. Higher conductivity correspond with higher salinity. Temperature and salinity (fluid conductivity) has a strong dependence on the actual flow in the borehole and shall only be recorded together with the flow tool. The flowtool and the temperature and salinity tool is stacked together to ensure this issue. The fluid parameters are often different if they are logged before, during or after pumping, and the logname index F, U and E corresponds to logging before, during and after pumping/injection. Repeated logruns after pumping is sometimes an opportunity to monitor even the smallest vertical water flow. This issue can be very important for the interpretation of the fluid logs since there can be big differences between salinity of borehole water and formation water in zones with vertical flow and baseflow. Zones with constant values for TEMP and EC35 is an

Log names	Description
	indicator for vertical flow of some amount. Specially the TEMP should be increasing with depth due to the general thermostatic gradient from surface and downhole.
RLLS, RLLD	Focused formation resistivity. Measurement with short penetration (RLLS), and deep penetration (RLLD). Usefull as both lithological log and quality check of the borehole construction. The top of the tool is insulated together with app. 4m og the logging cable. This construction can disturb data from bottom of casing and about 4m below. The influence de-pends on the type of casing material, i.e. steel or plastic.
ILS, ILD	Electromagnetic induction. Recorded as dual induction where ILD measure with deep penetration and ILS with short penetration. Useful as both lithological log and quality check of the borehole construction. The electromagnetic induction is almost the inverse function of the focused formation resistivity. The difference is the measure method, and the resolution. Induction can measure though a plastic tube also, but is more averaged. The resolution of the focused formation resistivity is much better.
GEO	Graphic presentation of the geological description of the sediment samples.
WELL	Graphic presentation of the borehole construction.
Tolk GEO	Interpreted version of the ”GEO” track (in case of mismatch between the reported results and the measured results.
Tolk WELL	Interpreted version of the ”WELL” track (in case of mis-match between the reported results and the measured results.

Tabel 3-3: Description of presented logdata in the logsheets

3.7 Processing

Spikes and suspect values are trimmed.

NGAM is recorded in all tools for depth match. Depth is also checked at reference point when the tool returns. Depth matching is added if needed.

3.8 Delivery

The following documents is attached to this report according to the Appendix list below:

- PDF plot in 1:100 if printed on A3 paper size.
- PDF plot in 1:1000 if printed on A3 paper size.
- WellCAD file (*.WCL) to read with a WellCAD viewer.
- Log Ascii Standard file (*.LAS). Textfile with data.

The WellCAD file can be read, and zoomed, with a free WellCAD viewer downloaded from: http://www.alt.lu/downloads.htm

PB0901_20160823_GEOPHYSICAL-BOREHOLELOG_V0 1-100.PDF
PB0901_20160823_GEOPHYSICAL-BOREHOLELOG_V0 1-1000.PDF
PB0901_20160823_GEOPHYSICAL-BOREHOLELOG_V0.LAS
PB0901_20160823_GEOPHYSICAL-BOREHOLELOG_V0.WCL

Rev.	Date	Signature	Checked	Approved
0	2016-08-25	GA	UTN	UTN

Job
1100003017-034

RAMBØLL

Hannemanns Allé 53
DK-2300 Copenhagen S
Tel. +45 5161 1000
Fax. +45 5161 1001

Malmberg Borrning AB
Geophysical borehole logging

Borehole PB0901
Vantamansvägen

Drawing:
PB0901
1:100

Logging information

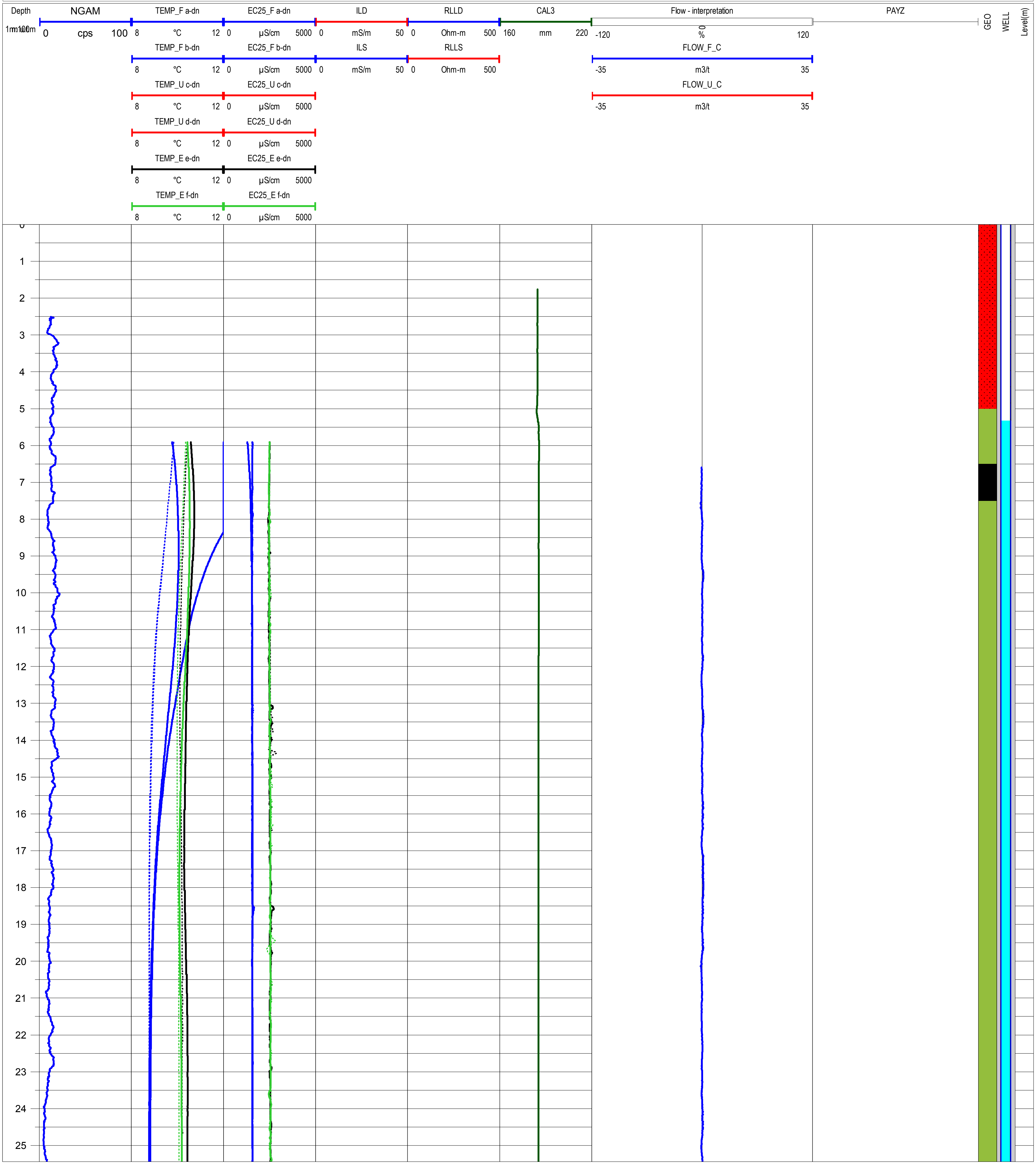
Loggingday/Staff	2016-08-23 / GA
Borehole no.	PB0901
Location	Yngsjö
Reference (Ref.)	Top steel lid (0.50m a.GL)
Reference level	-
Coordinates	X:6197401.514 Y:197446.42
Ref. system	-
Borehole diam.	183mm
Borehole fluid	Water
Casing type	Steel
Casing depth	71.5m b. ref. due to caliperlog
Depth report/meas	178m /174.5m b.ref. (soft bot.)
Static WL	5.33m b.ref.
Dynamic WL	15.38m b.ref.
Measured flow	Pumping 30m3/h

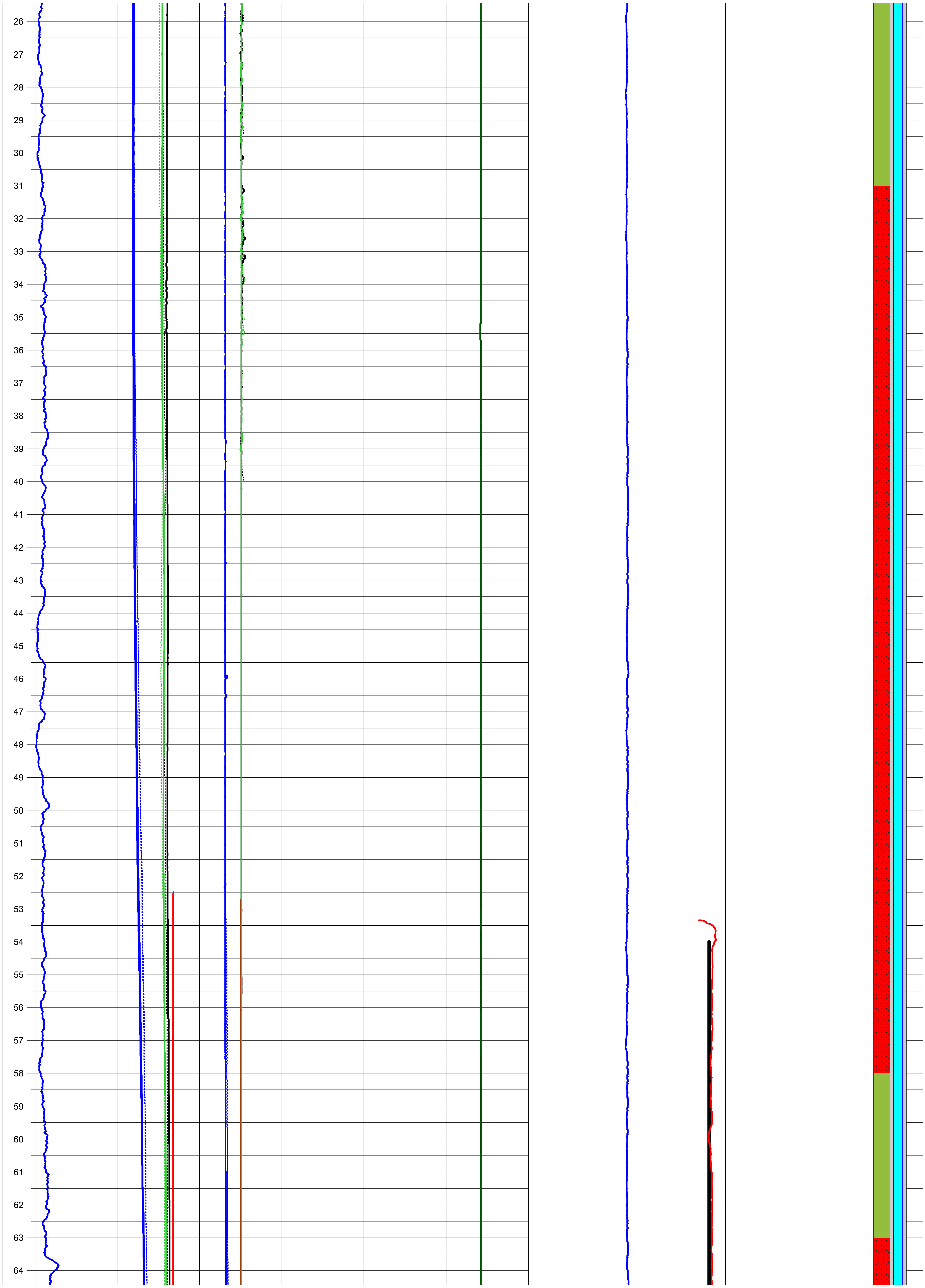
Comments:
Dotted EC25 and TEMP curves are uphole logging.

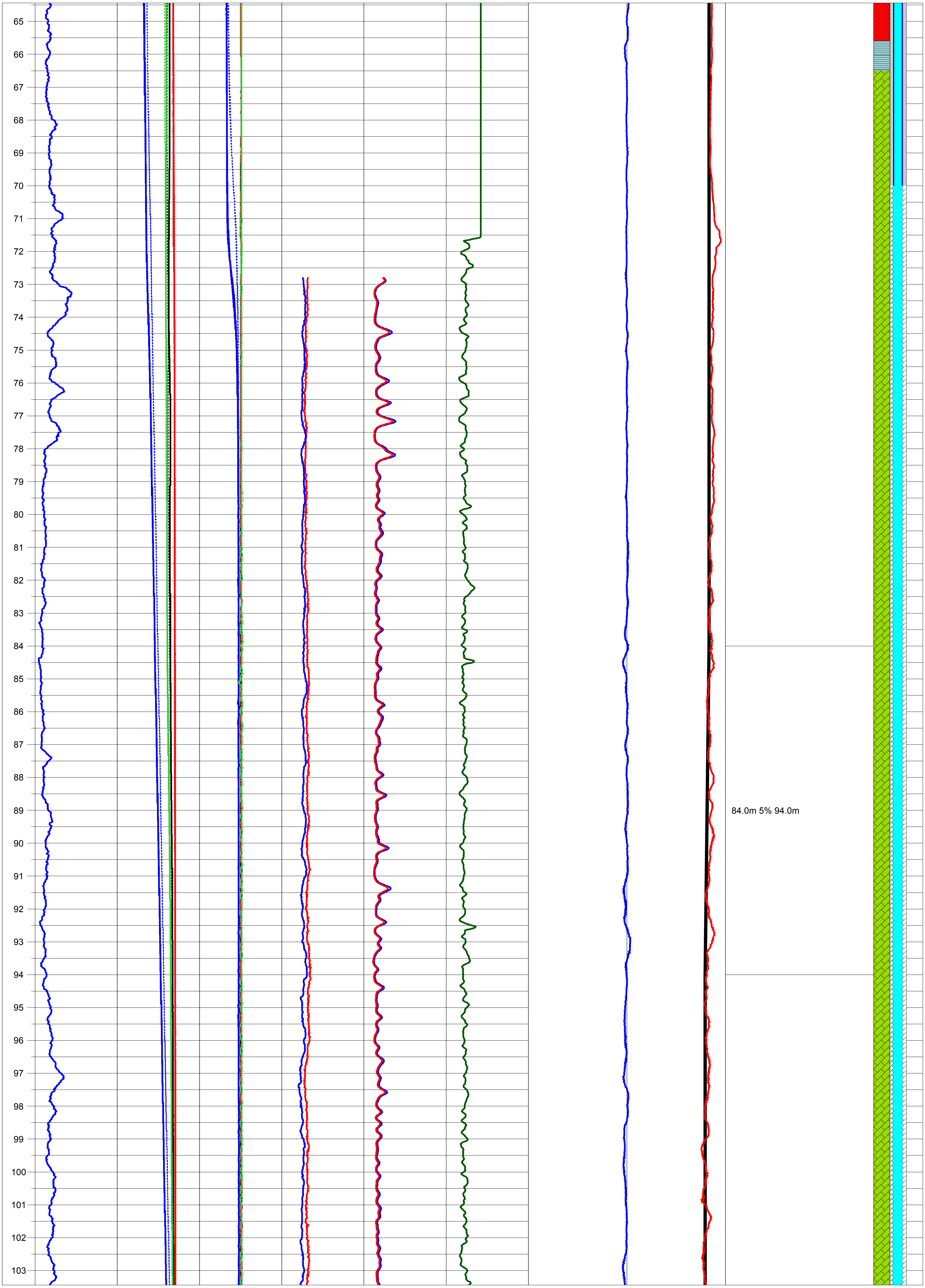
Logging programme

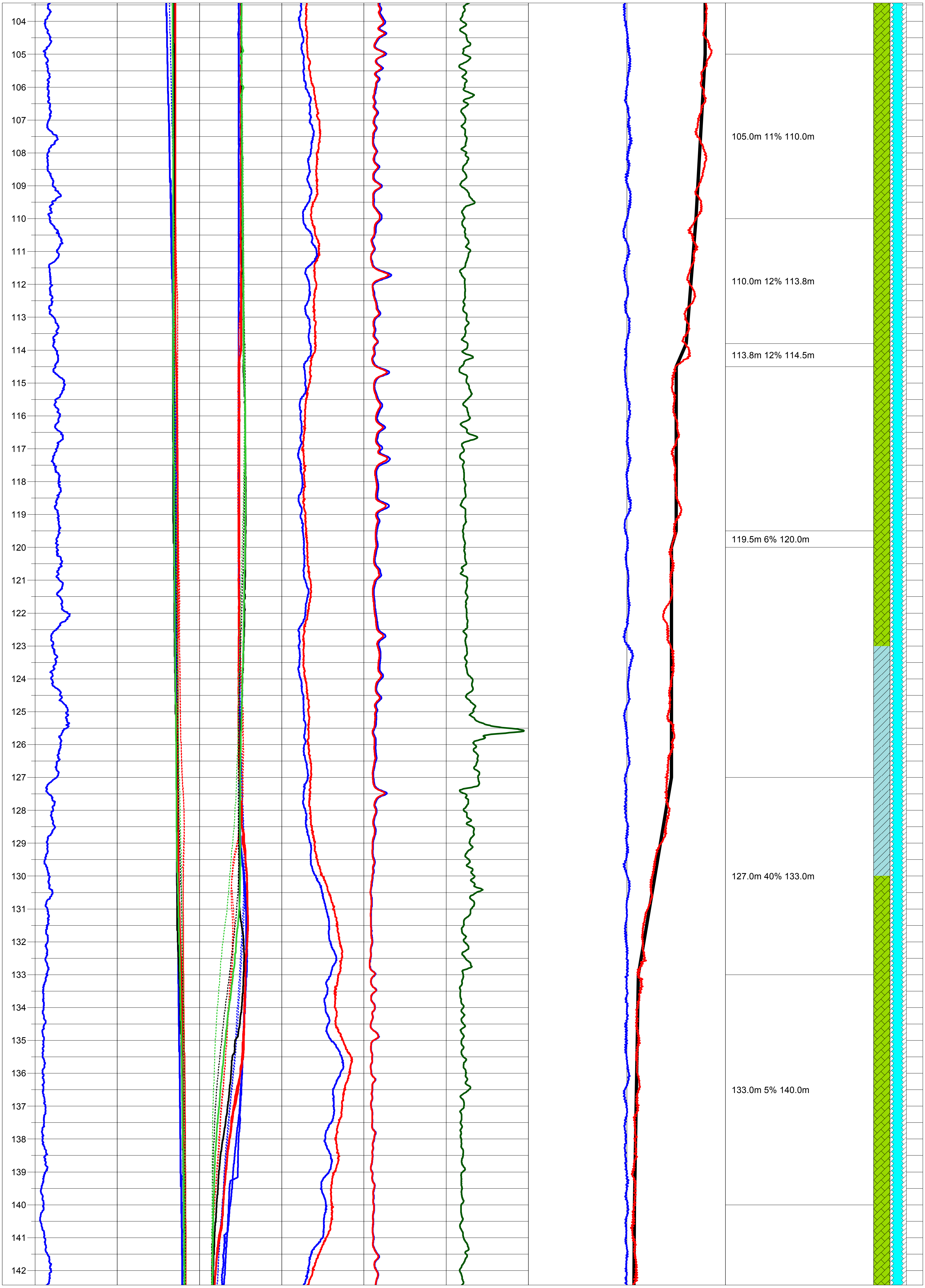
Logname	Description
NGAM	Natural gamma
RLLD / RLLS	Focused formation resistivity (RLLD=Deep,RLS=Short)
ILD / ILS	Electromagnetic induction (ILD=Deep,ILS=Short)
CAL3	3 arm caliper
OPTV	360° digital image of borehole wall
AKTV	Acoustic image from acustic televiewer (Refer to "Index" below)
HARD	Hardness calculated from the AKTV image (Refer to "Index" below)
INCL / AZ	Accelerometer inclination / Magnetometer azimuth
GEO / WELL	Reported lithologi / Technical construction
TEMP	Fluid temperature (Refer to "Index" below)
EC25	Elektric conductivity of fluid @ 25°C (Refer to "Index" below)
FLOW	Vertical flow. Upward flow direction defined as positive values (Refer to "Index" below)
PAYZ	Interpretated flowzones

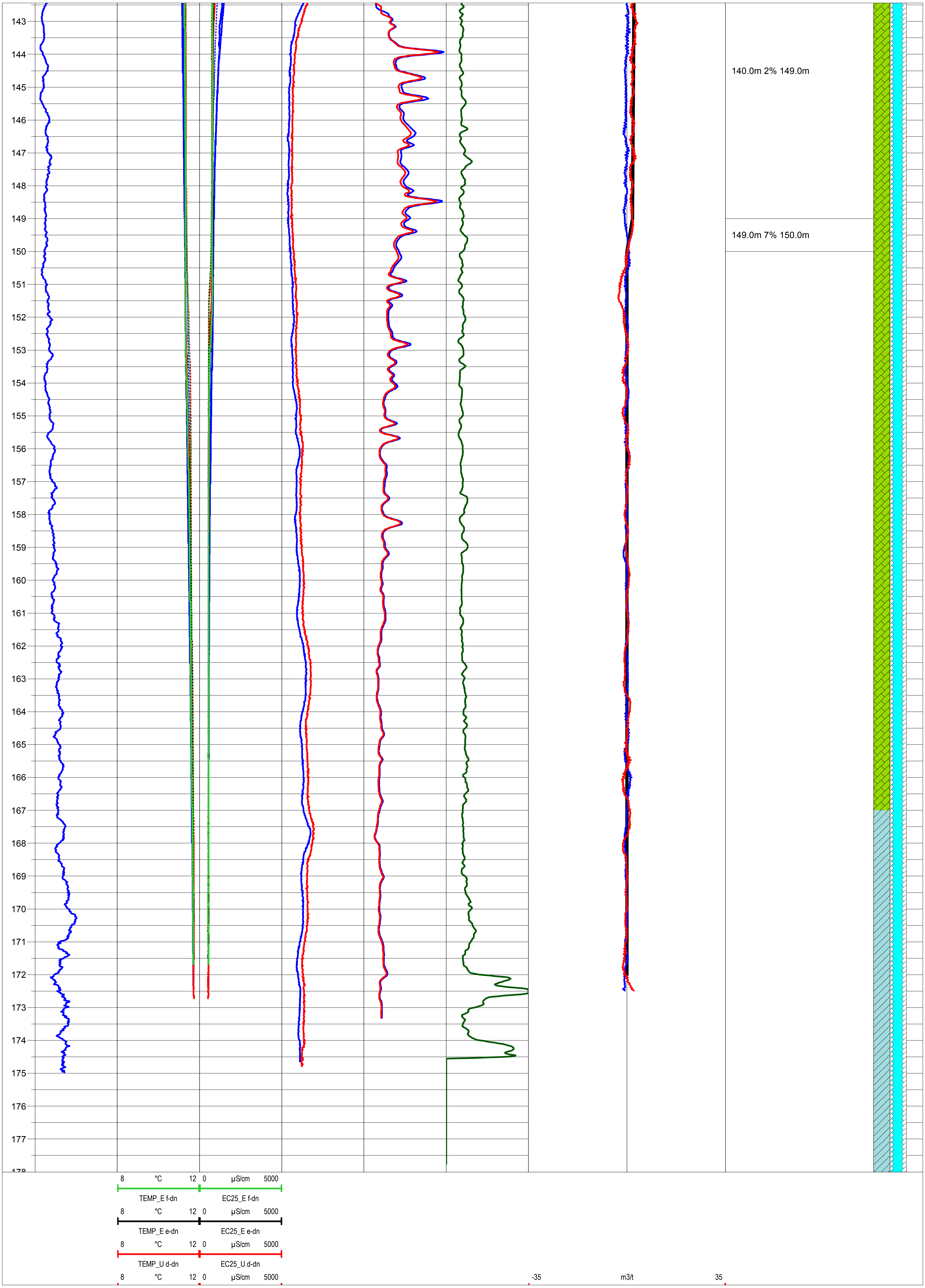
Index:
I = Inside surface of tube. Y = Ouside surface of plastictube
MN, GN, H or X: Aligned to magn.north, geog.north, high side or no orientation
F, U or E: Measured before, during or after pumping/injection
D: Difference flow, calculated as "FLOW_U - FLOW_F"
c: Flowyield, calculated from vertical velocity and caliperi




26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64


65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
84.0m 5% 94.0m


104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
105.0m 11% 110.0m
110.0m 12% 113.8m
113.8m 12% 114.5m
119.5m 6% 120.0m
127.0m 40% 133.0m
133.0m 5% 140.0m


143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
140.0m 2% 149.0m
149.0m 7% 150.0m
8 °C 12 0 µS/cm 5000
TEMP_E f-dn EC25_E f-dn
8 °C 12 0 µS/cm 5000
TEMP_E e-dn EC25_E e-dn
8 °C 12 0 µS/cm 5000
TEMP_U d-dn EC25_U d-dn
8 °C 12 0 µS/cm 5000
-35 m3/t 35

		TEMP_U c-dn	EC25_U c-dn				FLOW_U_C			
		8 °C 12	0 µS/cm 5000	0 mS/m 50	0 Ohm-m 500		-35 m3/t 35			
		TEMP_F b-dn	EC25_F b-dn	ILS	RLLS		FLOW_F_C			
1m:100m	0 cps 100	8 °C 12	0 µS/cm 5000	0 mS/m 50	0 Ohm-m 500	160 mm 220	-120 % 0 120			
Depth	NGAM	TEMP_F a-dn	EC25_F a-dn	ILD	RLLD	CAL3	Flow - interpretation	PAYZ	GEO	WELL	Level(m)

Rev.	Date	Signature	Checked	Approved
0	2016-08-25	GA	UTN	UTN

Job
1100003017-034

RAMBOLL
Hannemanns Allé 53
DK-2300 Copenhagen S
Tel. +45 5161 1000
Fax. +45 5161 1001

Malmberg Borrning AB
Geophysical borehole logging

Borehole PB0901
Vantamansvägen

Drawing:
PB0901
1:1000

Logging information

Loggingday/Staff	2016-08-23 / GA
Borehole no.	PB0901
Location	Yngsjö
Reference (Ref.)	Top steel lid (0.50m a.GL)
Reference level	-
Coordinates	X:6197401.514 Y:197446.42
Ref. system	-
Borehole diam.	183mm
Borehole fluid	Water
Casing type	Steel
Casing depth	71.5m b. ref. due to caliperlog
Depth report/meas	178m /174.5m b.ref. (soft bot.)
Static WL	5.33m b.ref.
Dynamic WL	15.38m b.ref.
Measured flow	Pumping 30m3/h

Comments:
Dotted EC25 and TEMP curves are uphole logging.

Logging programme

Logname	Description
NGAM	Natural gamma
RLLD / RLLS	Focused formation resistivity (RLLD=Deep,RLS=Short)
ILD / ILS	Electromagnetic induction (ILD=Deep,ILS=Short)
CAL3	3 arm caliper
OPTV	360° digital image of borehole wall
AKTV	Acoustic image from acustic televiewer (Refer to "Index" below)
HARD	Hardness calculated from the AKTV image (Refer to "Index" below)
INCL / AZ	Accelerometer inclination / Magnetometer azimuth
GEO / WELL	Reported lithologi / Technical construction
TEMP	Fluid temperature (Refer to "Index" below)
EC25	Elektric conductivity of fluid @ 25°C (Refer to "Index" below)
FLOW	Vertical flow. Upward flow direction defined as positive values (Refer to "Index" below)
PAYZ	Interpretated flowzones

Index:
I = Inside surface of tube. Y = Ouside surface of plastictube
MN, GN, H or X: Aligned to magn.north, geog.north, high side or no orientation
F, U or E: Measured before, during or after pumping/injection
D: Difference flow, calculated as "FLOW_U - FLOW_F"
c: Flowyield, calculated from vertical velocity and caliperi