Volve

15/9-F-15 D

Petrophysical (static) well evaluation

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1 Introduction

Objective of the producer 15/9-F-15 D was to drain remaining oil in the Upper Hugin formation north of well F-14 and downflank north of injector F-5. The presence of remaining oil in the Upper Hugin was recently proved by well 15/9-F-11 B well results.

15/9-F-15 D was to be geosteered in oil-bearing Upper Hugin. The objective was to establish a sufficient productive reservoir length, while minimizing exits into overlying Heather Formation or fully drained Hugin Thief zone below.

2 Summary

15/9-F-15 D was side-tracked from F-15 with KOP @ 1380m MD RKB. TD @ 4685 m MD RKB.

Top Hugin was encountered 3 m shallower than prognosed.

Baker Hughes' AziTrak and NearBit GR were used for geosteering.

Even if zonation has been considered as uncertain in parts of the well, the major part of the drilled Hugin section seems to be Upper Hugin. The well seems however to have encountered Middle Hugin (Thief Zone) twice and have also one Heather exit within Hugin.

Upper Hugin Fm. is oil filled, and main parts of Middle Hugin are as expected flooded.

Flooded intervals are given in table in chapter 4.7. A flag curve showing flooded intervals is named FLOODED_FLAG (in flooded intervals is FLOODED_FLAG = 1), and plotted as turquoise intervals in track no. 8 in the CPI plot.

Oil Down To (ODT) = 4595.5 m MD RKB / 3143.5 m TVD MSL, which is not in conflict with the observed ODT (= 3145 m TVD MSL) in the main field.

Averages for Hugin are given in table in chapter 5.

Since there is a huge contrast between the very saline Hugin formation water and the fresh, low saline Utsira formation (injection) water, 3 cases with different formation water salinity are presented in the CPI in order to illustrated the impact on water saturation. The details of these cases are given in the header of the CPI.

LWD log data is of good quality.

7 intervals have been perforated. These are listed in table below and plotted as light green intervals in the rightmost track (no. 18) in the CPI (chapter 6).

15/9-F-15 D PERFORATIONS					
Run no.	**Depth [m MD RKB]**	**Date**	**Shot Density**	**Open / Closed**	**Formation**
1	4582 - 4594	09.01.2014	4SPF	Open	Hugin
2	4524 - 4536	10.01.2014	4SPF	Open	Hugin
3	4110 - 4122	11.01.2014	4SPF	Open	Hugin
4	4022 - 4034	12.01.2014	4SPF	Open	Hugin
5	3890 - 3902	13.01.2014	4SPF	Open	Hugin
6	3853 - 3859	14.01.2014	4SPF	Open	Hugin
7	3825 - 3831	14.01.2014	4SPF	Open	Hugin

3 Data Acquisition and QC

3.1 Logging While Drilling (LWD)

The LWD logging contractor for the entire well was Baker Hughes.
Mud type in the 8 ½” reservoir section was OBM.
No cores were taken.

		15/9-F-15 D LWD Run Summary						
		Contractor: Baker Hughes						
LWD Run	**Hole Section [inch]**	**Logging service (tool combination)**	**Pass**	**Pass direction**	**Logging speed**	**Bit depth Interval [m MD RKB]**	**Logging interval [m MD RKB]**	**Remark**
1	17 1/5	OnTrak / ZoneTrak G	Drill	Down	ROP	1380 – 2618	1339 – 2615	Good logging run.
2	12 1/4	OnTrak	Drill	Down	ROP	2618 – 3299	2552.3 – 3279.9	Good logging run.
3	8 1/2	AziTrak / LithoTrak / ZoneTrak G / CoPilot	Drill	Down	ROP	3299 – 4685	3225 - 4682	Good logging run including 1 re-log.

Re-log in Bit depth interval 4337 – 4376 m MD RKB (LWD run # 3), was logged while backreaming 11 – 12 hrs after being drilled.

Memory data:
All data was in memory. The data quality is in general good.

3.2 Electrical Wireline Logging

No electrical logging performed in open hole.

4 Petrophysical Evaluation

Petrophysical evaluation is performed according to the Volve petrophysical field model, described in report: "Sleipner Øst and Volve Model 2006, Hugin and Skagerrak Formation, Petrophysical Evaluation". November 2006. Author: Elin Solfjell, Karl Audun Lehne.

The petrophysical evaluation software used is Geolog, and the Geolog project is SLEIPNER_OST (at Stavanger server: FROST_SVG).

4.1 Porosity

Total porosity, PHIF (ϕ_F), is derived from the density log which is calibrated to overburden corrected core porosity for wells drilled with either OBM or WBM.

The Neutron log, NPHI, has been used to correct for varying mud filtrate invasion.

$$\phi_F = \phi_D + A \times (NPHI - \phi_D) + B$$

where:

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}} \quad \text{[fraction]}$$

ρ_{ma} is the matrix density [g/cm^3]
ρ_b is the measured bulk density (RHOB), [g/cm^3]
ρ_{fl} is the pore fluid density [g/cm^3].

A and B are regression coefficients.

NPHI: Neutron log in limestone units [fraction]

4.2 Shale volume

To determine VSH, the standard model VSH_{GR} from linear GR relationship is applied:

$$VSH = VSH_{GR} = \frac{GR - GR_{\min}}{GR_{\max} - GR_{\min}}$$

where:

GR = gamma ray log reading [API]
$GR_{\min}$ = GR reading in clean sand [API]

GR_{max} = GR reading in shale [API]

VSH is used quantitatively in deriving permeability, and quantitatively indirectly in Netsand cutoff.

In order to pick GR_{min} and GR_{max} in a more objective way, and to avoid over-estimating of VSH, GR is "normalized" against VSHDN (VSH from density / neutron) by cross plotting GR versus VSHDN. VSHDN is considered to be the most reliable shale indicator (except in intervals dominated by mica and heavy minerals). This shale indicator compares porosity derived from the Density log with porosity from the Neutron log. If the Neutron log reads higher porosity than the density, this is believed to be due to the hydrogen content of present clay minerals.

VSHDN is derived from the response equation for the Neutron log:

$$VCLDN = \frac{NPHICS - (PHIT * HIFL)}{HICL}$$

$$VSHDN = \frac{VCLDN}{(1 - PHISH)}$$

where:

VCLDN = Dry shale volume from density / neutron logs [fraction]
NPHICS = Neutron log corrected to sandstone matrix [fraction]
PHIT = Total log porosity [fraction]
HIFL = Hyrdogen Index to fluid
HICL = Hydrogen Index to clay
PHISH = Shale porosity [fraction]

In table below are the general parameters used in Hugin Fm. for deriving VSHDN, given the assumption that Kaolinite is the dominant clay mineral:

VSHDN Parameters		
HIFL (oil / water)	**HICL**	**PHISH**
0.95 / 1	0.5	0.07

4.3 Water saturation

Water saturation is calculated using Archie equation, giving a total water saturation:

$$Sw_t = \left(\frac{a \times R_w}{\phi_F^m \times R_t} \right)^{\frac{1}{n}}$$

where:

a = Archie (tortuosity) factor
R_w = resistivity of formation water [Ohmm]
ϕ_F = Total porosity [fraction]
m = cementation exponent
R_t = true resistivity [Ohmm]
n = saturation exponent

4.4 Permeability

The horizontal log permeability, KLOGH, is derived from the following equation based on multivariable regression analysis between log porosity and shale volume ("normalized" against VSHDN) against overburden corrected core permeability:

Heather Fm.: $KLOGH = 10^{(2+8\times PHIF-9\times VSH))}$

Hugin Fm.: $KLOGH = 10^{(2+8\times PHIF-9\times VSH))}$

4.5 Composite curves

The following composite curves are used for the petrophysical evaluation:

GR*	: GRCFM from OnTrak (GR from Schlumberger's MWD PowerPulse Gamma Ray in 15/9-F-15 above 1349 m MD RKB)
RHOB	: BDCFM from LithoTrak
NPHI	: NPCKLFM from LithoTrak
PEF	: DPEFM from LithoTrak
RT	: RPCEHM from OnTrak
DRHO	: DRHFM from LithoTrak
CALI	: CALCM from UltraSonic Caliper, part of LithoTrak

* Note that in the 17 ½" and 8 ½" sections the NearBit GR (NBGRCFM) is spliced into GR for the ~ 9 last meters.
Note also that any re-scaling ("normalization") of the GR curve is documented in Logtek's info file; WLC_COMPOSITE_2_INF_1.PDF which is stored in Petrobank.

Note also in general that the final «average» density curve - RHOB (BDCFM) - from Baker is weighted with respect to which of the 16 sectors / bins that provide the best density measurement (smallest standoff).

NPHI (NPCKLFM) is in limestone units, Caliper and salinity corrected and filtered.

The composite curves were created by Logtek from the memory data delivered by Baker Hughes.

Logtek's RDEP (Resistivity Deep) curve = RPCELM, named RD in the OW Volve project.
Logtek's RMED (Resistivity Medium) curve = RPCEHM, named RM in the OW Volve project.

No depth shifting has been applied, except in limited overlap intervals around kick off depth and between NBGRCFM and GRCFM (GRCFM being the reference curve). These depth shifts and the splicing of the individual runs are reported in Logtek's info file; WLC_COMPOSITE_2_INF_1.PDF.
All depths are referenced to Driller's depth.

Logtek's general "philosophy" with respect to depth shifting in the transition zone between a mother well and a kick off well is as follows: aim to keep the stop-coupled depths as shallow as possible, preferably at KOP. But sometimes it has to be sat deeper (a few meters deeper, preferably in a shale if possible) due to a) if overlapping curves are not on depth at KOP, or b) if the depth shifts have been so large, that the logs else will be too compressed. This "philosophy" also applies of course for depth shifting in overlap between hole sections.

4.6 Evaluation parameters

The following evaluation parameters are used for calculation of porosity, shale volume and water saturation:

15/9-F-15 D Evaluation parameters		
	Formation name	
Parameter	Heather Fm.	Hugin Fm.
ρ_{ma}	2.66	2.65
ρ_{fl}	1	0.9
A	0	0.4
B	0	0.01
$GR_{\min}$	5	5
$GR_{\max}$	90	110
a	1	1
m	2	*)
n	2	2.45
*) $m = 1.865 \times \left(KLOGH^{(-0.0083)}\right)$		
R_w = 0.07 ohmm @ 20 ^oC.		
Temperature gradient = 2.6 ^oC / 100 m. Reservoir temp.: 111 ^oC @ 2800 m TVD MSL.		

Note that the RT curve used for saturation calculation, has been edited in intervals where RPCEHM is affected by polarization horns or is saturated. This editing is kept on a specific curve in Geolog, named RT_EDIT.

4.7 Flag curves

Netsand flag:

Cutoffs on PHIF and VSH are used to determine Netsand; SAND_FLAG = 1.
Hugin Fm.: SAND_FLAG = 1 when PHIF > 0.10 and VSH < 0.50.

These cut offs correspond to a overburden corrected core permeability of 0.5 mD, and are also applied for the Heather Fm.

In addition some manual editing might have been performed on the SAND_FLAG curve.

Carbonate volume:

A varying carbonate volume curve, VCARB, has been made instead of a carbonate flag curve. This carbonate volume curve has been calculated from an empirical relationship:

$$VCARB = \left[\frac{0.2 - (PHIF + 0.3 \times VSH)}{0.2} \right] \times \left(1 - PHIF - VSH\right)$$

Note that the volume carbonate is just meant to be used visually / qualitatively, and not for any quantitative purposes.

The above VCARB equation was however not applied in the intervals: 4498 – 4521 m MD RKB, 4563 – 4582 m MD RKB, 4597.5 – 4632 m MD RKB. Here this relationship was applied instead: VCARB = 0.15 x VSH.

Coal flag:

No coal layers were observed in the well.

Flooded interval flag:

A flag curve showing flooded intervals is named FLOODED_FLAG. When flooded intervals, FLOODED_FLAG = 1.

Flooded intervals are given in table 4.7 below, and are also plotted as turquoise intervals in track no. 8 in the CPI plot for 15/9-F-15 D.

15/9-F-15 D FLOODED INTERVALS		
DEPTH [m MD RKB]	**DEPTH [m TVD MSL]**	**ZONE**
3570.6 – 3582.5	2883.0 – 2886.1	Hugin 2.3 (9)
3594.3 – 3601.2	2889.1 – 2890.8	Hugin 3.1 (10)
3633.0 – 3726.4	2897.6 – 2916.0	Hugin 2.3 (9), Hugin 2.2 (8)
4309.0 – 4461.0	3086.2 – 3118.5	Hugin 2.3 (9)

Table 4.7

5 Petrophysical results

Tables below in this chapter are showing average values of Net/Gross (N/G), total porosity (PHIF), total water saturation (SW) and horizontal permeability from logs (KLOGH) in Netsand.

Note that the reported water saturation averages are from case calculated with pure Hugin formation water salinity, as if no flooding.

15/9-F-15 D Averages								
Formation / Zone	**Top** **[m MD RKB]**	**Base** **[m MD RKB]**	**N/G** **[fraction]**	**PHIF** **[fraction]**	**SW*** **[fraction]**	**KLOGH arithmetic [mD]**	**KLOGH harmonic [mD]**	**KLOGH geometric [mD]**
Heather	3465	3484	0.018	0.122	0.153	102	74	85
	4564	4580.3	0	-	-	-	-	-
	4597.6	4685	0.305	0.123	0.955	0.1	0.1	0.1
	Weighted Heather averages:		0.220	0.123	0.942	2	0.1	0.1
Hugin	3484	4564	0.786	0.209	0.264	409	3	115
	4580.3	4597.6	0.798	0.149	0.339	103	49	70
	Weighted Hugin averages:		0.786	0.208	0.265	404	3	114
Upper Hugin	3484	3560	0.826	0.195	0.188	188	2	46
	3726	4244.6	0.669	0.224	0.171	156	2	63
	4462	4564	0.696	0.180	0.310	138	2	69
	4580.3	4597.6	0.798	0.149	0.339	103	49	70
	Weighted Upper Hugin averages:		0.693	0.212	0.193	156	2	61
Middle Hugin (“Thief Zone”)	3560	3726	0.942	0.216	0.336	1049	7	360
	4244.6	4462	0.972	0.191	0.393	506	41	206
	Weighted Middle Hugin averages:		0.959	0.202	0.367	737	13	261
Hugin 3.3 (12)	3484	3518	1.000	0.190	0.186	313	102	171
	3726	3814	0.956	0.212	0.147	403	149	319
	4521	4564	0.963	0.172	0.324	170	60	120
	4580.3	4597.6	0.798	0.149	0.339	103	49	70
	Weighted Hugin 3.3 (12) averages:		0.951	0.193	0.204	306	93	198
Hugin 3.2 (11)	3518	3539	0.621	0.179	0.250	6	0.5	2
	3814	3887	0.434	0.199	0.145	47	0.6	8
	4056.8	4109	0.044	0.177	0.227	1	0.3	0.5
	4499	4521	0	-	-	-	-	-
	Weighted Hugin 3.2 (11) averages:		0.279	0.192	0.176	33	0.5	5
Hugin 3.1 (10)	3539	3560	0.748	0.220	0.150	66	6	34
	3589	3602	0.527	0.194	0.499	7	0.3	2
	3887	3974	0.592	0.243	0.155	97	5	62

	3981 4109 4462	4056.8 4244.6 4499	0.523 0.977 0.799	0.228 0.235 0.192	0.166 0.195 0.292	69 84 93	2 2 0.8	33 64 32
	Weighted Hugin 3.1 (10) averages:		0.746	0.229	0.196	82	2	47
Hugin 2.3 (9)	3560 3602 3974 4299.6	3589 3640 3981 4462	0.957 0.967 0.757 0.994	0.210 0.228 0.133 0.194	0.261 0.139 0.232 0.442	2614 1872 0.1 633	29 549 0.1 90	1471 1153 0.1 340
	Weighted Hugin 2.3 (9) averages:		0.978	0.200	0.361	1053	4	409
Hugin 2.2 (8)	3640 4244.6	3726 4299.6	0.990 0.905	0.214 0.184	0.438 0.226	267 95	154 15	211 41
	Weighted Hugin 2.2 (8) averages:		0.957	0.203	0.367	203	35	115

***** Note that the reported water saturation averages are from case calculated with pure Hugin formation water salinity, as if no flooding.

6 CPI plot of evaluated curves and raw data

Remarks regarding F-15 D CPI:

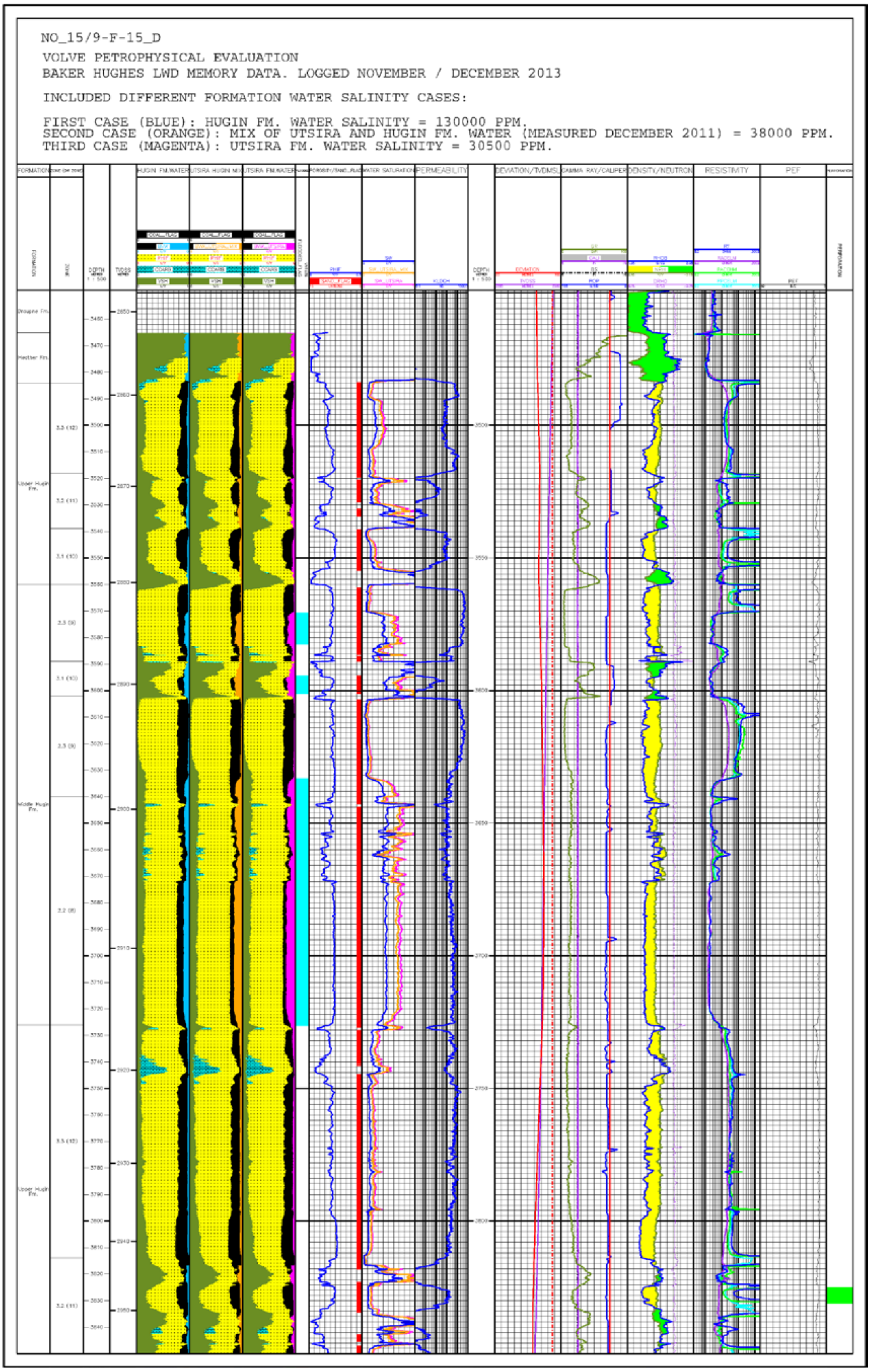
Note that the CPI is separated in 3 parts for better visualization.

Note also that the CPIs include 3 different formation water salinity cases:
First case is Hugin formation water salinity,
second case is a mixture of Hugin and Utsira formation water salinity,
third case is pure Utsira formation water salinity.

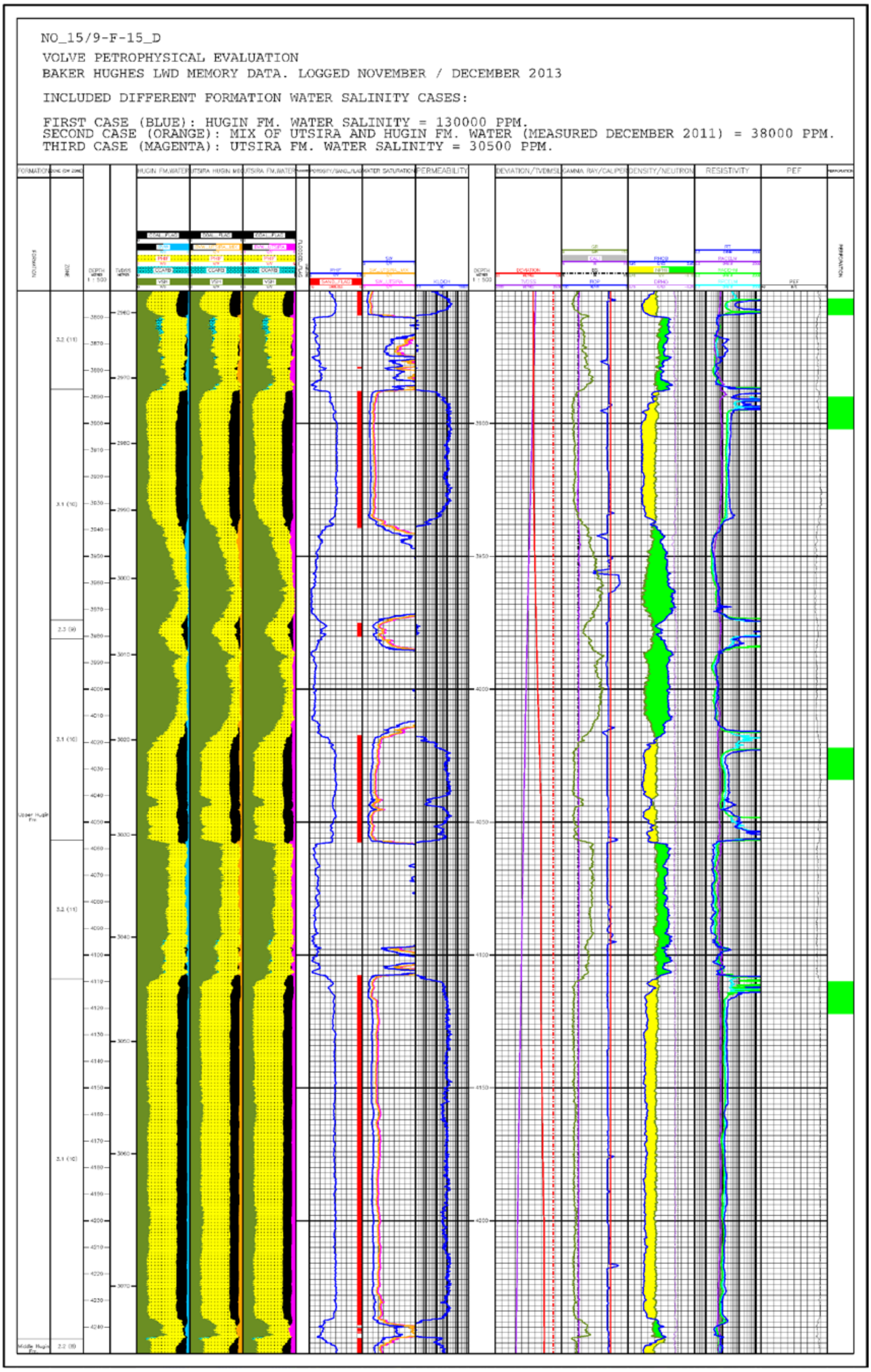
The details in difference and color coding are explained in the header of the CPIs. There is a huge contrast between the very saline Hugin formation water and the fresh, low saline Utsira formation water (injection water), and the different cases illustrate the impact on the water saturation.

Note also that the salinity is changed in the whole evaluated interval, and that all other parameters are kept unchanged.

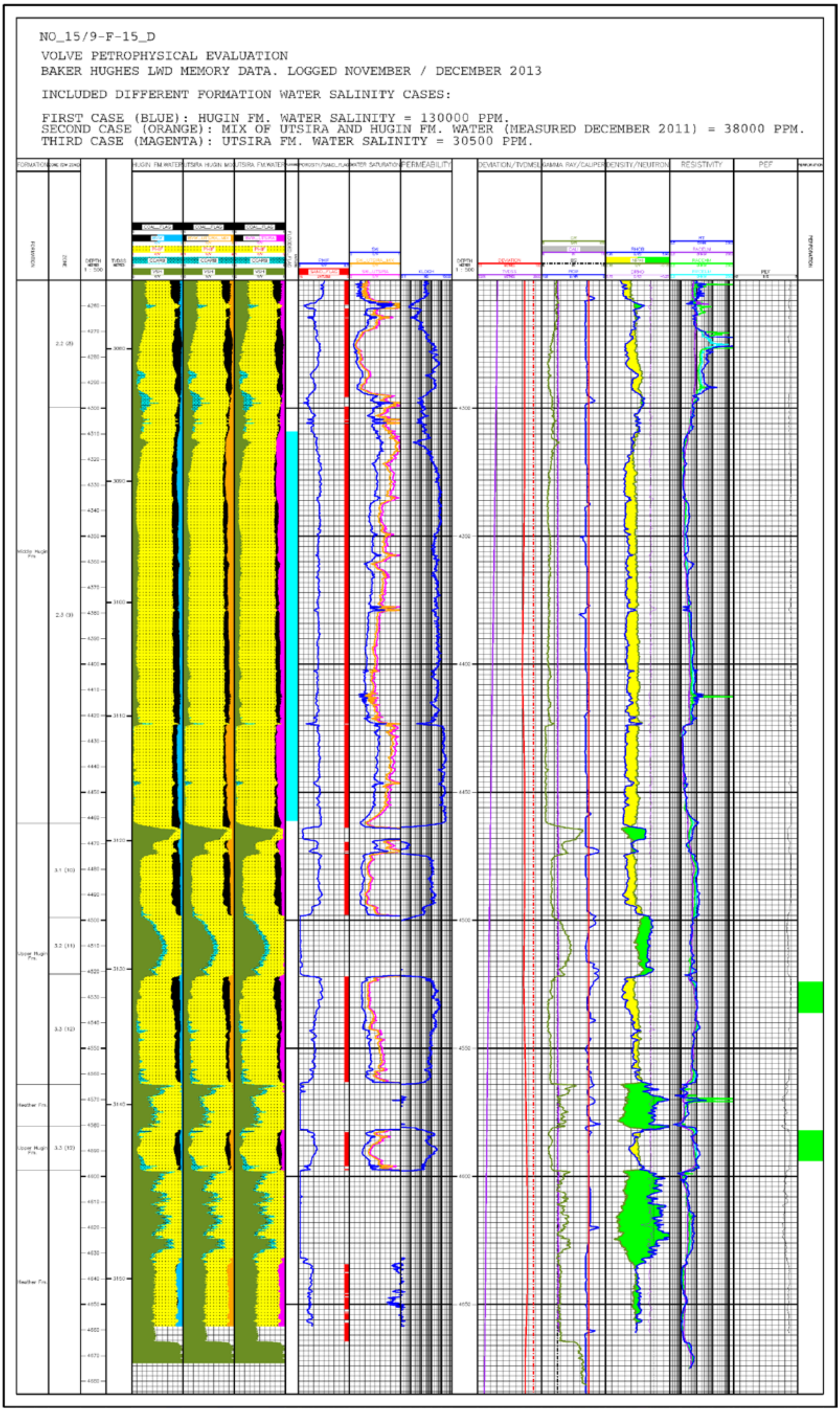
CPI plot 15/9-F-15 D, interval 3449 – 3850 m MD RKB



CPI plot 15/9-F-15 D, interval 3850 – 4250 m MD RKB



CPI plot 15/9-F-15 D, interval 4250 – 4685 m MD RKB



7 References

1. “Sleipner Øst and Volve Model 2006, Hugin and Skagerrak Formation, Petrophysical Evaluation”. November 2006. Author: Elin Solfjell, Karl Audun Lehne.
2. Logtek’s info file for well 15/9-F-15 D: WLC_COMPOSITE_2_INF_1.PDF