Petrophysical Report of the Dinantian Carbonates in the Dutch Subsurface

Report by SCAN

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Ministerie van Economische Zaken en Klimaat
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TNO
Interreg North-West Europe DGE-ROLLOUT

Contents

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Dit rapport is een product van het SCAN-programma en wordt mogelijk gemaakt door het Ministerie van Economische Zaken en Klimaat

WELL DATA O18-01

Company Name: Placid International Oil Ltd

Well Name: 0-18a-1

Field Name: Wild Cat

Country: The Netherlands

Field Location: offshore

Longitude: 52*07’55.65” X

Latitude: 02*55’27.18” Y

Maximum Hole Deviation: 4.2(deg)@3049m

Elevation of Kelly Bushing: 32.2m

Elevation of Ground Level: - 36.4m

Elevation of Derrick Floor: 32.2m

Permanent Datum: MSL

Elevation of Permanent Datum: MSL

Log Measured from: 940m to TD

Maximum recorded temperature: 95 degC

TD: 3051m

Dinantian evaluation in O18-01 (1586-2915 m MD)

Log Quality, edits and depth shifts

The GR-Sonic-Laterolog digital file is off by approximately 8.8 m compared to the composite and a similar distance compared to the prints. Therefore, the composite has been used for the evaluation.

The density is affected by numerous washouts and in almost all washouts, it is invalid or at least very suspicious. The neutron and sonic are less affected by these washouts but they are also occasionally affected. The MSFL is also responding to the washouts but this is less of an issue as it is primarily a support log.

The density has been extensively edited in the Dinantian and should not be used for any interpretation except for the seismic. The edits will be obvious as they are straight lines or very close to straight lines.

The sonic is edited in the reservoir due to some significant cycle skipping and other effects in conjunction with wash outs. This has been done by calculating a synthetic sonic, one with Limestone matrix and one with Dolomite matrix from the resistivity porosity, see evaluation section below. With these and the neutron, a sonic has been constructed in intervals with the largest effects.

The mud is KCl with quite high salinity (62 000 ppm Cl) resulting in a high background Potassium concentration caused by the Potassium in the mud through the mostly clean Dinantian carbonate. This effect will also be larger in the more washed out boreholes and in the 12 ¼" hole compared to in the 8 ½" hole.

The spectral GR curves have been spliced after the correction of the K-curve in the 12 ¼" hole, see below.

Log corrections

The corrected neutron, CNC, has too negative porosity in the 8 1/2" hole below 1617 m and this is probably mostly due to the hole size correction that pulls it down. The CNC has been corrected by adding 0.009 to get the neutron porosity mostly on the positive side of 0 below 1617 m. The neutron in the 12 ¼" hole does not require correction.

A correction of the K-curve (Potassium) has been applied in the 12 ¼" hole to make this part of the Potassium curve to align with the Potassium curve in the 8 ½" hole. The correction is -1 %.

Evaluation of Dinantian (1586-2915 m MD)

Porosity has been calculated from x-plot porosity of the Sonic and the Neutron and the density-neutron. Both these porosities have quality issues in the washed-out intervals and therefore need to be complemented with a porosity derived from the resistivity.

The deep resistivity is a combination of the deep induction and the deep laterolog, being spliced at approximately 1619 m. The induction is heavily affected by the high salinity borehole and is not recording a correct formation resistivity in the upper part of the Dinantian and is therefore not suitable for calculation of porosity above 1619 m.

The Picket plot result in an estimate of the Rw of 0.05 ohmm at 2900 m where the most reliable porosity is the density-neutron x-plot porosity in the range 2-6 %, see fig 1 below.

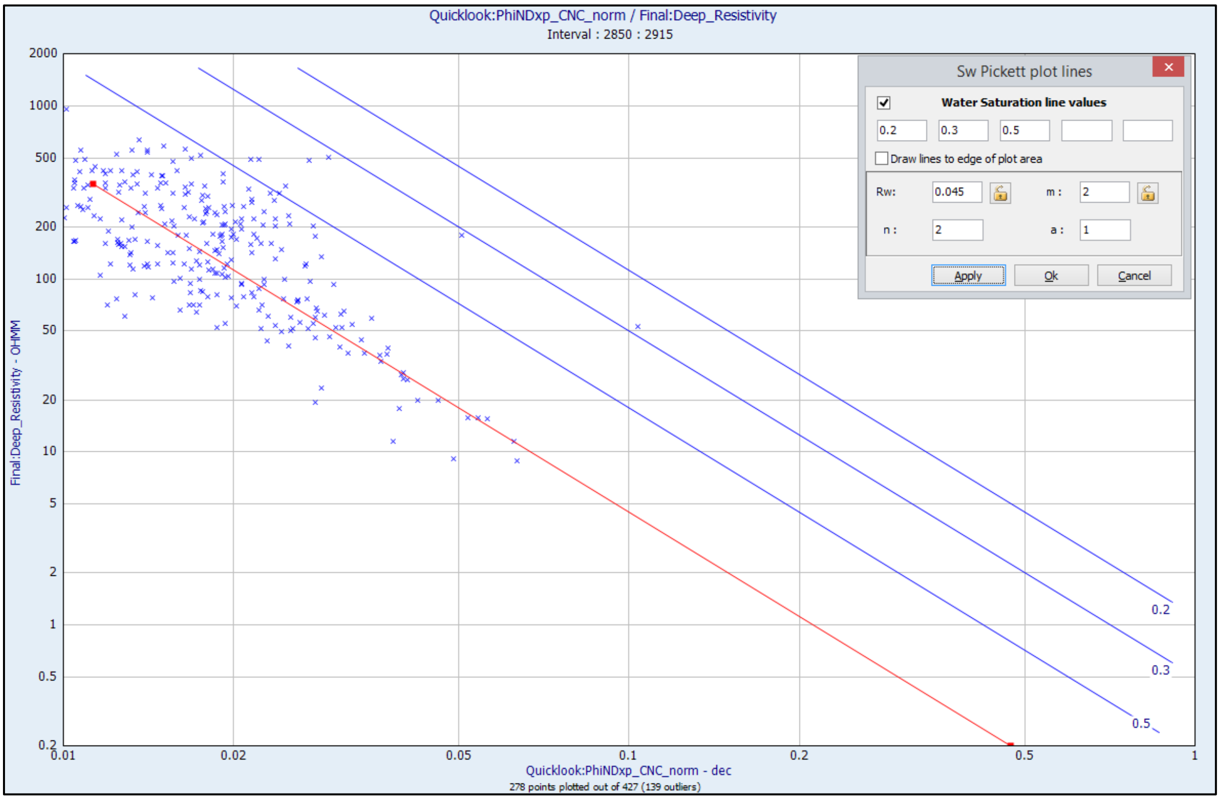


Figure 1. Picket plot of deep laterolog vs neutron-density x-plot porosity in interval 2850-2915 m MD.

The formation temperature at 2900 m is 98 deg C, see formation temperature derivation below. The water resistivity of 0.05 ohmm at 98 deg C correspond to a salinity of 60000 ppm. Applying Arp's formula, the Rw is corrected to formation temperature. The resistivity porosity is calculated from the deep resistivity and the formation water resistivity (Rw) using Archie's equation with an m of 2:

Resistivity porosity = (Rw/Deep_Resistivity)**0.5

The final porosity is a spliced version of the three calculated porosities as follows:

1586-1616.96 m: Density-Neutron x-plot porosity

1616.96-1620.47 m: Sonic-Neutron x-plot porosity

1620.47-2915 m: Resistivity porosity

The reason for choosing the density-neutron in the upper part is that this porosity has the best match to the core porosity, while the sonic-neutron porosity is too low. In the short section where the sonic-neutron is used, the reason is that it is judged that the density-neutron result in a too high porosity. In the entire 8 ½" hole, the resistivity-based porosity is used. This may result in some sections having a slightly overestimated porosity. However, as this primarily applies to porosity below 2 % this is not considered a serious issue, the rock is tight.

A clay indicator has been calculated from the spliced K-curve with a 0% clay at 0.55 % and 100 % clay at 5.55 % K. In other wells a 100 % clay value of 5 has been used, however, due to the Potassium in the mud, the upper bound has been increased by adding 0.55.

The resulting equation is:

Clay Indicator = -0.11+0.2*K (K in %)

A cut off using a clay indicator value of 0.1 has been applied.

Result

The result of the evaluation can be seen in the log evaluation plot. In the middle depth track are the cored intervals and the core recovery indicated in brown. In the evaluation track 9 is the Clay Indicator and core grain density, in track 10 the porosity on a 0 to 10 % scale with the test interval indicated in black. In track 11 is the core permeability and in track 12 is the calculated lithology described in this report displayed.

The sums and averages for this well is provided in the table below with a Clay Indicator cut off of 0.1.

Gross	Net	Net/Gross	Average Porosity	Average Clay Indicator	Average Porosity times net	Normalized Porosity*net	Porosity cut-off
MD	MD	MD					
m	m	fract	fract	fract	m	fract	fract
1329,0	1262,94	0,950	0,007	0,026	9,42	1,00	0,00
1329,0	315,77	0,238	0,014	0,033	4,46	0,47	0,01
1329,0	31,24	0,024	0,026	0,045	0,80	0,08	0,02
1329,0	4,11	0,003	0,043	0,056	0,18	0,02	0,03
1329,0	1,37	0,001	0,064	0,057	0,09	0,01	0,04
1329,0	1,07	0,001	0,070	0,051	0,07	0,01	0,05
1329,0	0,76	0,001	0,076	0,047	0,06	0,01	0,06
1329,0	0,46	0,000	0,085	0,035	0,04	0,00	0,07
1329,0	0,46	0,000	0,085	0,035	0,04	0,00	0,08
1329,0	0,15	0,000	0,093	0,032	0,01	0,00	0,09
1329,0	0,00	0,000			0,00	0,00	0,10

The second column from the right is a normalized product of average porosity and net (Average porosity*net/Average Porosity*net at no porosity cut off) to enable plotting in the same graph as the other parameters, see figure 2 below.

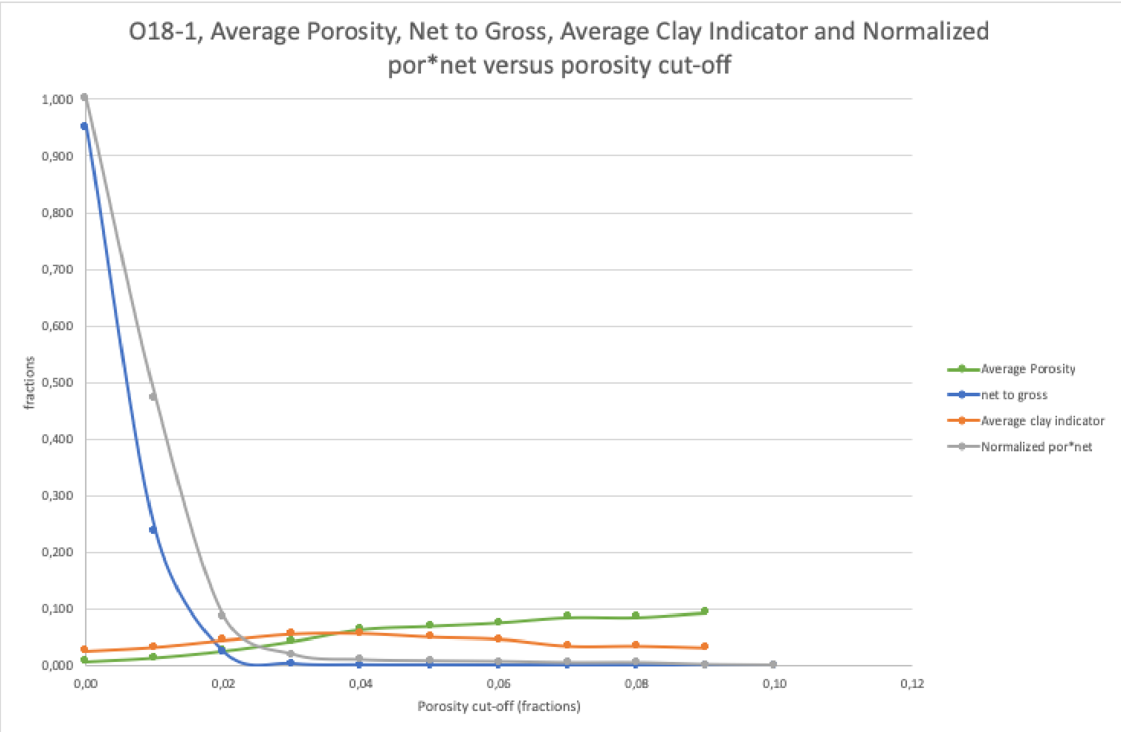


Figure 2. Average porosity, net-to-gross, clay indicator and normalized porosity*net thickness for increasing porosity cut-off

The graph illustrates the very rapid decrease in net to gross and in the product of average porosity and net (Normalized por*net). There is almost no porosity above the 3 % porosity cut-off. The average of the clay indicator initially increases and have a maximum around 3-4 % porosity cut off, something that could possibly indicate that the slightly more porous intervals have a higher clay content and that they could be associated with infill in karst. The porosity at no porosity cut-off is 0.7 %, a very low value but consistent with many other wells.

Discussion

O-18 has the longest section of Dinantian of the wells evaluated, 1329 m. The upper part is dominated by very low porosity Limestone with some Dolomite. The highest porosity intervals tend to have a bit more Dolomite. Below 2370 m, the Dolomite content increases, with Dolomitic sections interlaced with Limestone dominated sections, down to 2765 m. Below this depth it is Dolomite.

The clay content is a bit uncertain due to the use of Potassium mud. The uppermost section down to approximately 1630 m has a higher clay content and this is also the case for most of the basal section below 2875 m. A higher clay content is possible for the most porous parts in the section 2170-2215 m where the highest porosity intervals have a higher Potassium signal. However, it is quite possible that this is due to aggregation of mudcake that could cause an increase in apparent Potassium content. Similar spikes in Potassium can be observed in several of the slightly higher porosity intervals.

The porosity is very low in this well and the number of intervals with porosity exceeding 2 % are limited and, in most cases, very short. Many sections have porosity in the 0-1 % range. At the top of the reservoir there are porosity up to 4 % but this is associated with higher clay content and is probably tight. At approximately 1617 m there is a 2 m interval with higher porosity. In the interval 1800 – 1900 m there are several porosity spikes above 2 % with the most prominent at 1880 m. The porosity in this 1 m interval exceeds 10 % and is associated with a high density around 3000 kg/m3. There are several of these high density spikes in the interval 1857-1895 m and they mostly appear to have low resistivity. This could be caused by Pyrite and the porosity could therefore be overestimated in some of the porosity spikes in this interval, although all porosity tools do indicate similar porosities.

In the interval 1990-2060 m there are some thin spikes, less than 1 m, with porosity exceeding 2 % with the highest at 2060 m with up to 5 %.

The highest porosity interval is 2170-2180 m where the porosity exceeds 2 % over 10 m with the highest porosity, 11.5 %, at the top of the interval. This interval has some very sharp break outs and it is quite possible that this is caused by fractures. The erratic behavior of the logs is indicative of karsting possibly associated with fractures. Below this interval down to 2220 m there are several more very thin porosity spikes.

At 2430 m and at 2440 m there are two more minor porosity spikes exceeding 2 %.

The next porosity spike occurs at 2840 m. Below 2880 m down to 2912 m the porosity increases and is associated with an increase in clay content. It is likely that the increase in clay content is the main cause of the increase in porosity and that the interval has no or very low permeability.

Many of the porosity spikes are associated with break outs (sharply larger hole, see caliper) and it is relatively likely that some of these are caused by fractures or karst.

Core Data

The well has been cored in the following intervals:

Core 1: 1181.4-1199.7 m (Westphalian) (100 % recovery)

Core 2: 1199.7-1218 m (Westphalian) (97 % recovery)

Core 3: 1600.2-1610.9 m (Dinantian) (100 % recovery)

Core 4: 1610.9-1614.8 m (Dinantian) (100 % recovery)

Core 5: 2064.7-2076.1 m (Dinantian) (100 % recovery)

Core 6: 2612.4-2639.9 m (Dinantian) (100 % recovery)

Core 7: 3034.3-3051.4 m (Devonian) (100 % recovery)

Of the Dinantian cores, only core 3 (1600.2-1610.9 m) have core analysis performed. The porosity is in the range 0-2 % with majority below 1 %. Most of the core plugs have no detectable permeability (<0.01 mD), none have a permeability above 1 mD.

Flow potential

Well tests

One open hole well test (DST) was performed in the interval 1602-2862 m (5256-9392 ft).

The DST test string was run and the packer was set in the 9 5/8" casing at 1600.5 m (5251 ft). The well was lifted several times with Nitrogen but would not flow to surface. Some inflow was recorded with the pressure gauge at 2150 m. Lowest downhole pressure at 2150 m (2118 m TVDss) (7055.2 ft) recorded after N2 lift was 133 bar (1917 psig). The maximum pressure at this depth, before terminating the test, was 187 bar (2712 psig). A normal reservoir pressure at this depth would be approximately 215 bar.

With the very low porosity and no acid stimulation it is not surprising that the well had very limited inflow from the Dinantian.

During the test, one temperature measurement was recorded at 2150 m (7055 ft): 79.5 deg C (175 deg F)

Wireline Formation Tester (FMT)

One run with wireline formation tester (FMT) was done on 11 May 1991. All points were either seal failures or dry test (no inflow at all).

Test No	File No	Depth	Hydr. Press. Before	Hydr. Press. Before	Hydr. Press. After	Hydr. Press. After	Stabilised Pressure during test	Stabilised Pressure during test	Temp	Remark
		m	psig	bar	psig	bar	psig	bar	C	
2	3	2179,0	3476,4	240,7	3476,3	240,7	-	-	77,5	Seal failure
3	4	2180,0	3478,1	240,8	-	-	-	-	77,9	Dry test
1c		1783,0	2787	193,2	2788	193,2	12	1,8		Dry test
2a		1762,5	2755	191,0	2757	191,1	15	2,0		Dry test
2b		1762,3	2754	190,9	2755	191,0	-	-		Seal failure
3a		1758,0	2747	190,4	2749	190,6	-	-		Seal failure
3b		1757,8	2746	190,3	2748	190,5	18	2,3		Dry test, depth uncertain, 1747.8 m is stated.
4a		1678,5	2626	182,1	2628	182,2	-	-		Seal failure
4b		1678,2	2626	182,1	2626	182,1	16	2,1		Dry test
5		1645,0	2574	178,5	2574	178,5	18	2,3		Dry test
6		1492,3	2340	162,4	2339	162,3	17	2,2		Dry test
7		1489,0	2330	161,7	2333	161,9	19	2,3		Dry test
8		1465,0	2295	159,2	2296	159,3	19	2,3		Dry test
9		1180,0	-	-	1864	129,5	-	-		Sampled in hole enlargement to check
9		1180,0	1864	129,5	1865	129,6	-	-		

10		1179,0	1866	129,7	1865	129,6	-	-		pressure reading on Amerada.
11		1179,0	-	-	-	-	-	-		

Formation temperature

Table showing the maximum temperatures from the different logging runs in O18-01 at TD (3051 m).

Log	Depth	Log date	Time since circ.	Max Temp
	(m)		(hrs)	(deg C)
GR/DLL/AC	≈3020	9/5/1991	13	93
GR/SPEC/CDL/CNL	≈3030	10/5/1991	21	96
FMT	≈2720	11/5/1991	7	92
Dipmeter	≈3030	11/5/1991	14	96

Based on the first two logging runs the Horner extrapolated formation temperature is 101 deg C at 3020 m. Note that the two latter runs were made after a check trip with circulation and because the FMT was not run below 2720 m these two runs cannot be used for Horner extrapolation.

Table showing the maximum temperatures from the different runs in the 12 ¼" hole in O18-1 (1625 m)

Log	Depth	Log date	Time since circ.	Max Temp
	(m)		(hrs)	(deg C)
GR/DIFL/AC	≈1600	3/4/1991	6.5	58
GR/SPEC/CDL/CNL	≈1610	4/4/1991	10	63

Based on the maximum temperature measured on these two logging runs, the Horner extrapolation result in a formation temperature at approx. 1600 m of 73 deg C.

Table of temperature gradients based on the Horner derived formation temperatures using a sea bottom temperature of 8 deg C.

Depth	Depth TVDss	Temperature	Temperature gradient	Temperature gradient back to surface
m	m	Deg C	Deg C/m	Deg C/m
68.6	36.4	8		
1600	1568	73	0.042	0.042
3020	3019	101	0.019	0.031

Based on the temperature data, the temperature gradient is very high in this well down to 1600 m (1568 m TVDss) and below this depth, the gradient is much lower. The resulting temperature from surface to TD is close to normal with 31 deg C/km. Due to the large difference in the up-hole formation temperature gradient and the lower part, it is best to divide the temperature calculated in the well with one equation down to 1600 m and a different below this depth. The formation temperature gradient equations are as follows (a sea bottom temperature of 8 deg C has been assumed:

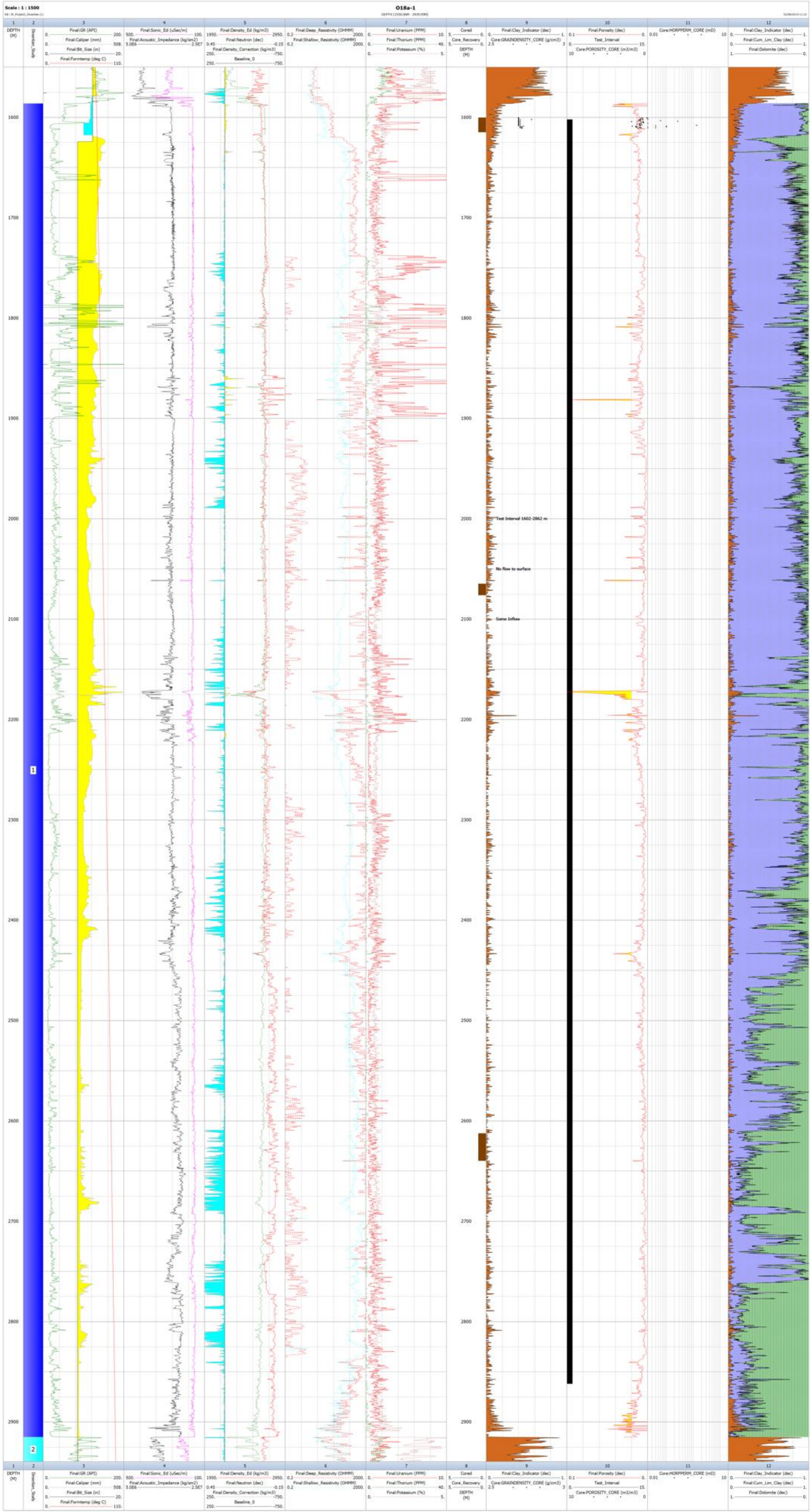
68-1600 m (36-1568 m TVDss)

Formation Temperature = 6.47 + 0.042428* TVDss

Below 1600 m (1568 m TVDss)

Formation Temperature = 42.76 + 0.019284 * TVDss

Evaluation plot O18-01



Well logging summary O18-01

OPERATOR:	Placid International		WELL LOGGING SUMMARY
WELL:	018a-1		
WELL BORE:	018a-1		
FIELD:			
PLATFORM:	offshore		
COUNTRY:	NETHERLANDS		
DRILL PERMIT #:			
WELL STATUS:	P and A		

Hole section:	File name:	Main Service:	Generic Logs	Service Company:	Mode:	Run #:	Sub file:	Run Type	Pass Direction (Up/Down)	Date:	Interval Top (m):	Interval Bot (m):	Remarks:
17 1/2"					EWL								
12 1/4"	GR-DIFL-AC	GR-DIFL-AC	GR-IND-Sonic Log	Western Atlas	EWL	1	1	Main	Up	03-April-1991	940	1624.2	
12 1/4"	GR-DIPLOG	GR-DIPLOG 4 arm	GR-DIPLOG	Western Atlas	EWL	1	2	Main	UP	04-April-1991	940	1624.2	
8 1/2"	GR-SDL-CN	GR-SDL-CN	GR-DEN-NEU Log	Western Atlas	EWL	2	3	Main	Up	04-April-1991	1125	1624	
8 1/2"	GR-CBIL	GR-CBIL	GR-Acoustic borehole image	Western Atlas	EWL	2	4	Main	Up	04-April-1991	940.5	1623.8	no data
8 1/2"	SL	SL	Spectral GR	Western Atlas	EWL	2	5	Main	Up	04-April-1991	1125.0	1624.1	
8 1/2"	GR-DLL-MLL-AC	GR-DLL-MLL-AC	GR-Dual Laterolog-Microlaterolog-Sonic	Western Atlas	EWL	2	6	Main	Up	09-MAY-1991	1616.2	3051.5	
8 1/2"	GR-SDL-CN	GR-SDL-CN	GR-DEN-NEU Log	Western Atlas	EWL	2	7	Main	Up	10-MAY-1991	1616.2	3051.5	
8 1/2"	SL	SL	Spectral GR	Western Atlas	EWL	2	8	Main	Up	10-MAY-1991	1616.2	3051.5	
8 1/2"	GR-FMT	GR-FMT	GR-Wireline Formation Tester	Western Atlas	EWL	2	9	Main	Up	11-MAY-1991	1096	2027.5	
8 1/2"	GR-DIPLOG	GR-DIPLOG 4 arm	GR-DIPLOG	Western Atlas	EWL	2	10	Main	Up	11-MAY-1991	1620	3050.0	

Appendix: Horner plots

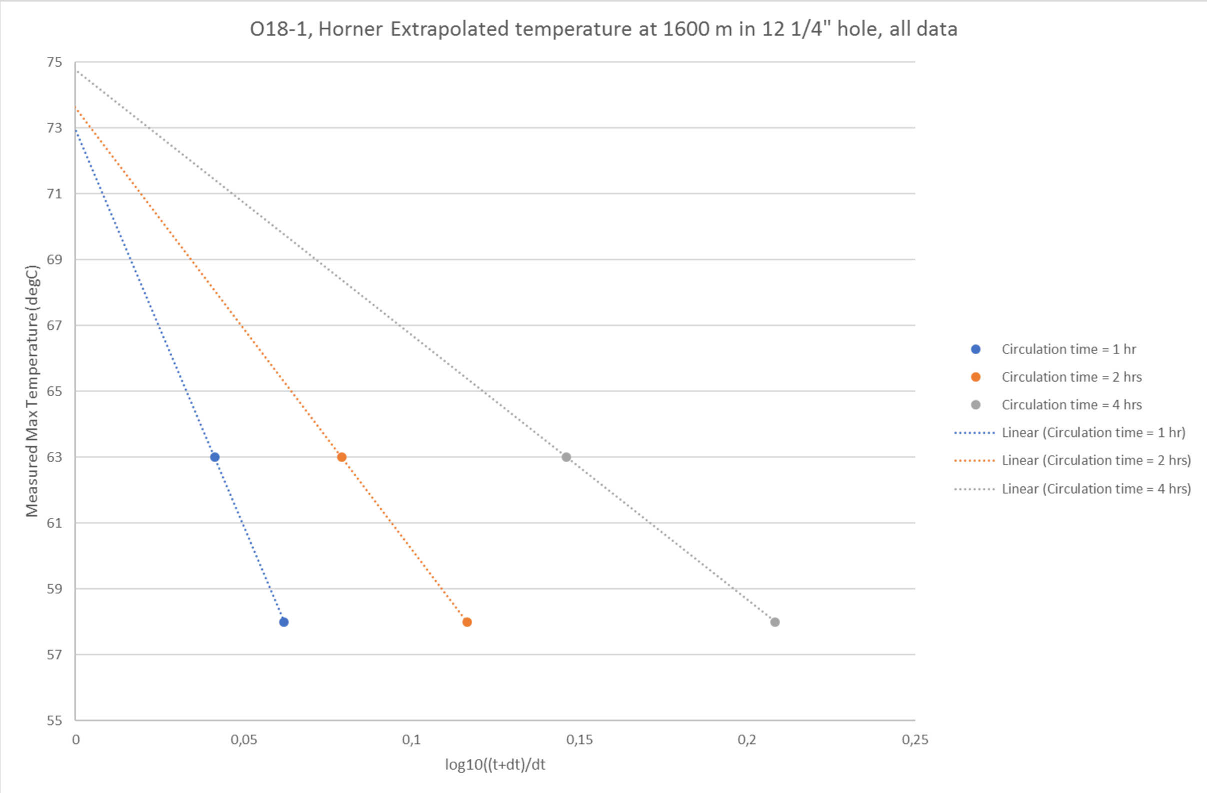


Figure 1. Horner plot at 1600 m

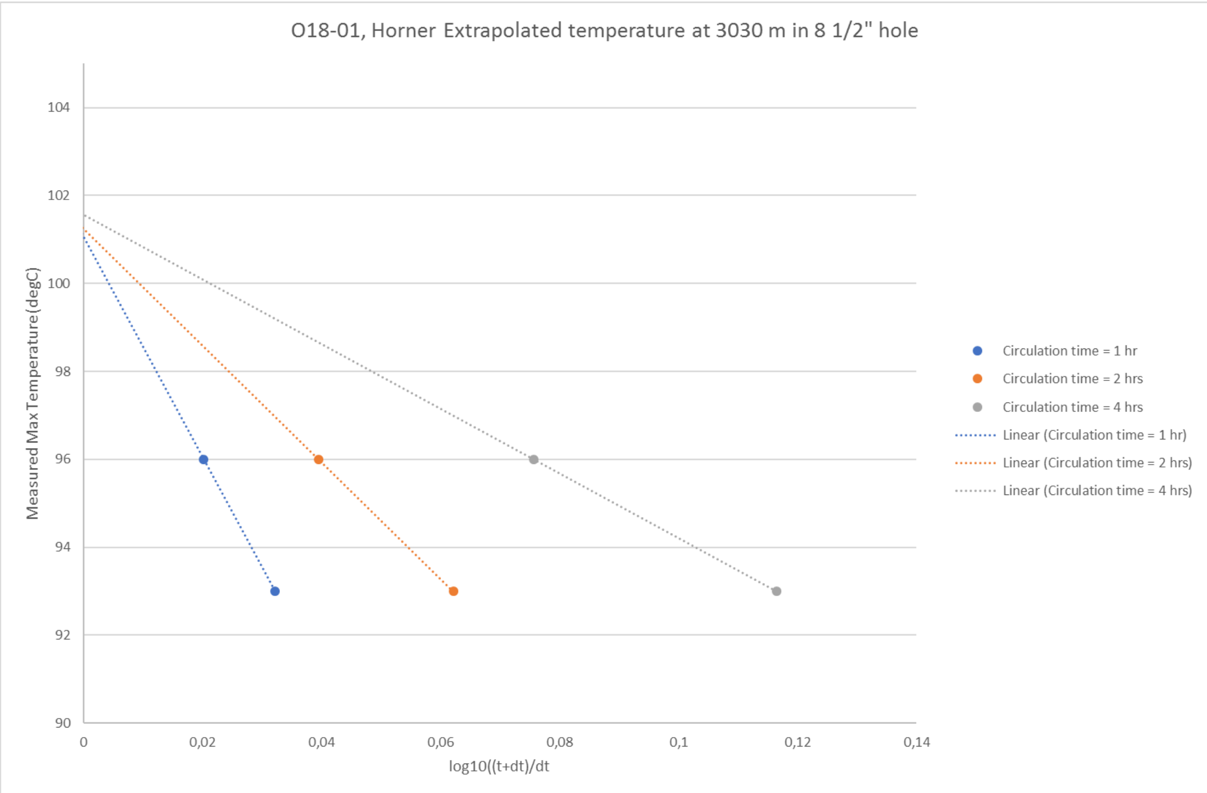


Figure 2. Horner plot at 3030 m

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