Petrophysical Report of the Dinantian Carbonates in the Dutch Subsurface

Report by SCAN

April 2019

Ministerie van Economische Zaken en Klimaat
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Contents

Report by Torbjörn Carlson

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

WELL DATA WSK-01

Company Name: NAM B.V.

Well Name: WSK-01

Field Name: Winterswijk

Country: The Netherlands

Field Location: onshore

Geological targets: Lower Carboniferous

Longitude: + 89786,98 X

Latitude: - 24729,61 Y

Maximum Hole Deviation: see deviation diagram

Elevation of Kelly Bushing: RT 44,61m

Elevation of Ground Floor: NAP

Elevation of Derrick Floor: NAP

Permanent Datum: NAP

Elevation of Permanent Datum: NAP

Log Measured from: GR from Surface other from 547.5m

MRT Maximum recorded Temperature: no value

TD: 5009.7m on 20.12.1977

Dinantian evaluation in WSK-01 (4243-4461 m)

Log quality, edits and depth shifts

The only curve existing on the composite is the sonic (dt) and it has been shifted compared to the sonic logs in many intervals. A check of the composite curve result in that the shifted composite curve overall better matches the neutron curve compared to the original log curves. It is therefore concluded that the composite sonic log is the main log curve to use and they have been shifted to match the composite sonic.

The digital files in the 8 ½” hole does not match the way the tools were run and for the deeper part the sonic log appear on the same file as the density-neutron logs, resulting in the GR of one or the other missing. On several files, the Laterolog has been added, although it was run on a separate run. This could indicate that the logs are digitized from the prints or film. The fact that there is no density correction curve, DRHO (FDCC), would support this.

Apart from the sonic from the composite, all other logs were spliced from the different runs.

On the deepest recorded laterolog, the deep laterolog curve had been erroneously named LLGD instead of LL9D, this has been corrected.

The LL9S was depth shifted in the interval 4050-4375 m to match the LL9. Note that this curve is not used in the evaluation.

The density curve is of very poor quality in the lower part of the 8 ½” hole, in the Devonian, and has been extensively edited with straight lines. Both the density and the sonic have been edited in the overburden. The density is more jagged compared to other logs even when the borehole is in good condition. In the lower part of the hole, this is possibly due to the high density of the rock, resulting in low count rates. Low count rates result in rapid fluctuations of the density and this effect is common in early density tools. In the Dinantian intervals there are a few intervals where the density probably is affected by rugged borehole but here the density has not been edited.

Sonic is overall of good quality and is only occasionally suspected to be affected by the rugged hole in the lower part of the 8 ½” hole. The same is the case for the Neutron.

Log corrections

None of the curves have been environmentally corrected.

Note that the neutron supplied by Schlumberger has been clipped at 0 porosity and therefore there is many zero values. It is possible that the neutron is reading a bit too low but with the clipping of it at zero this is difficult to confirm.

Evaluation of Dinantian (4243-4461 m MD)

Note that the top Dinantian is uncertain and that the top used in the evaluation is not according to the official NLOG top at 4275. The reason is that there are clear Dinantian age rock up to at least 4240 m. The reason for setting the top at 4232 m is that this is where there is a clear change from shale above to more lime dominated lithology, observed on the density-neutron. The top could also be at 4220 m, where there is a high density spike, probably Pyrite or Barite or possibly other heavy mineral.

Porosity has been calculated primarily from x-plot porosity of the Sonic and the Neutron curves. Density and neutron x-plot porosity has also been calculated as well as porosity from the different porosity curves using a matrix slowness of 160 us/m and fluid slowness of 620 us/m, density of 2710 kg/m3 (all Limestone properties) and a fluid density of 1190 kg/m3 based on the salinity of the formation is salt saturated. The Picket plot clearly indicate this to be the case using the sonic-neutron x-plot and the deep laterolog resistivity. The porosities based on the density should be treated with some caution.

The resistivity indicated that many intervals have very low porosity, close to 0 in some intervals, while the porosity derived from the other tools indicate some porosity, due to clay in the matrix. Therefore, porosity has also been calculated from the deep laterolog (LL9D) using a Rw based on a Picket plot of LL9D and the sonic-neutron x-plot porosity, figure 1.

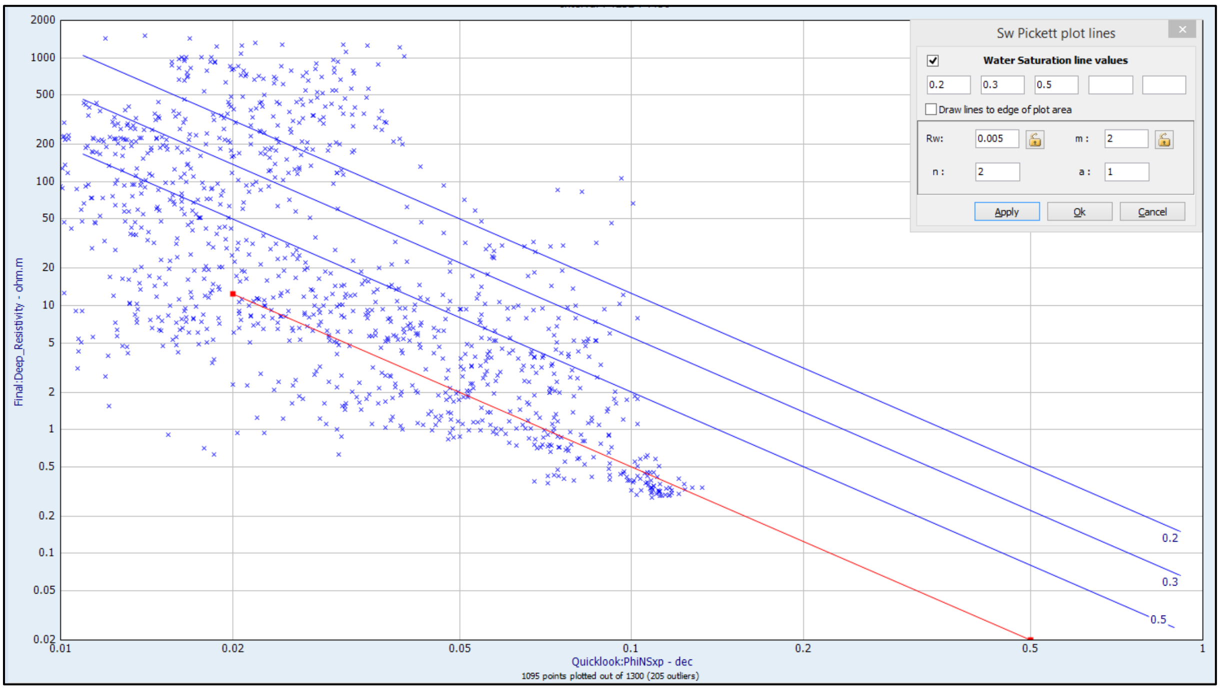


Figure 1. Picket plot of sonic-neutron x-plot porosity and deep laterolog resistivity in the interval 4232-4430 m (Avoiding the Pont d'Arcole shale below 4430 m)

Using the formation water resistivity derived from the Picket plot of 0.005 ohmm for the Dinantian (midpoint approximately 4300 m at 161 deg C) and calculating the porosity from the temperature corrected water resistivity, the resistivity-based porosity matches the sonic-neutron x-plot porosity closely, see figure 2.

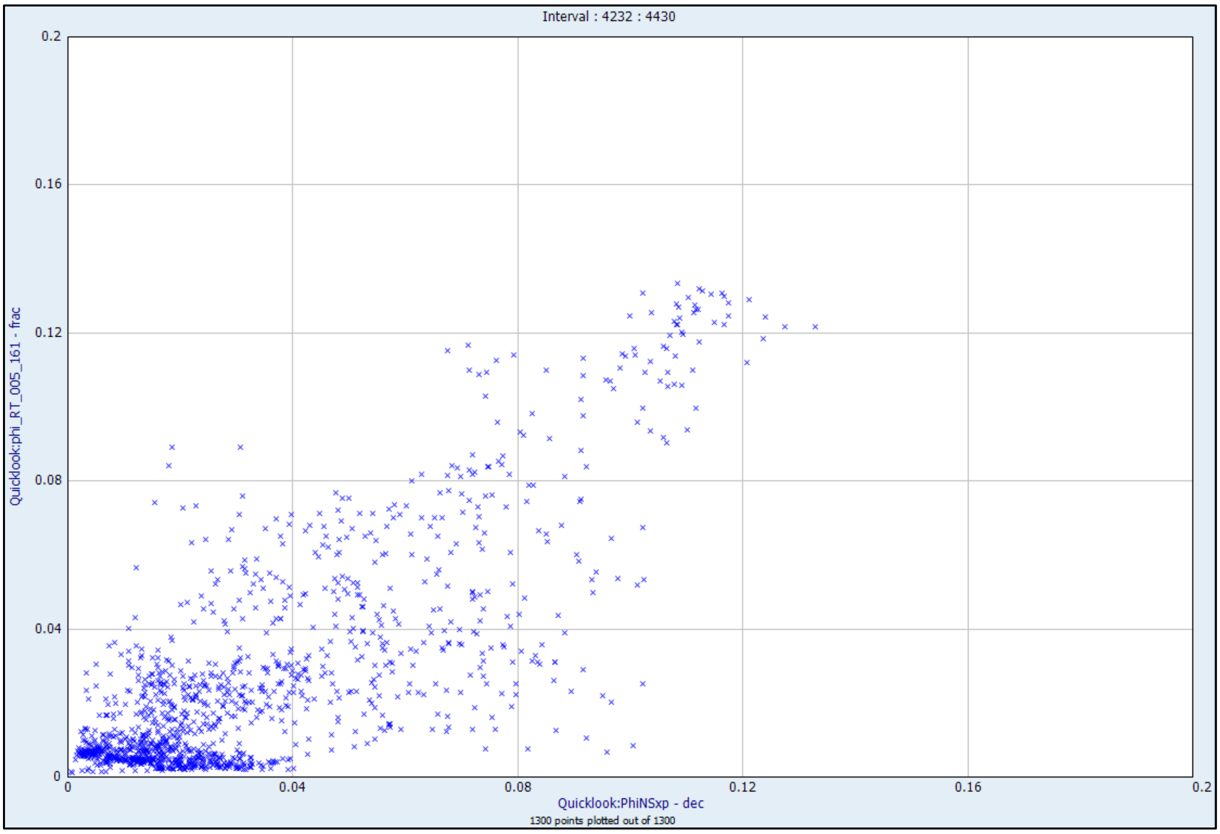


Figure 2. Resistivity derived porosity against sonic-neutron x-plot porosity.

The match between the two porosities is good, considering all the thin beds where there often are minor mis-matches. The final porosity chosen is therefore the porosity derived from the resistivity because it is not influenced by any hole irregularities in the borehole.

Because most Dinantian sections in the Netherlands have high concentrations of Uranium, in some intervals, the GR can generally not be used as a clay indicator. However, WSK-01 is an exception where there is a very clear relationship between the calculated porosity (with no cut offs) and the GR, see figure 3. Both from sonic-neutron and from density-neutron cross plots, the calculated higher porosity is caused by higher proportion of clay. Therefore, the good correlation between calculated porosity (from resistivity with no cut offs applied) and the GR leads to the conclusion, that for this well, the GR can be used as a clay indicator and that there probably is no significant Uranium content causing erroneous clay anomalies. The only anomaly on the plot, figure 3, is the carbonaceous shale at the base of Dinantian and the reason for this shale to have so low porosity is both compaction and a high proportion of lime in the matrix.

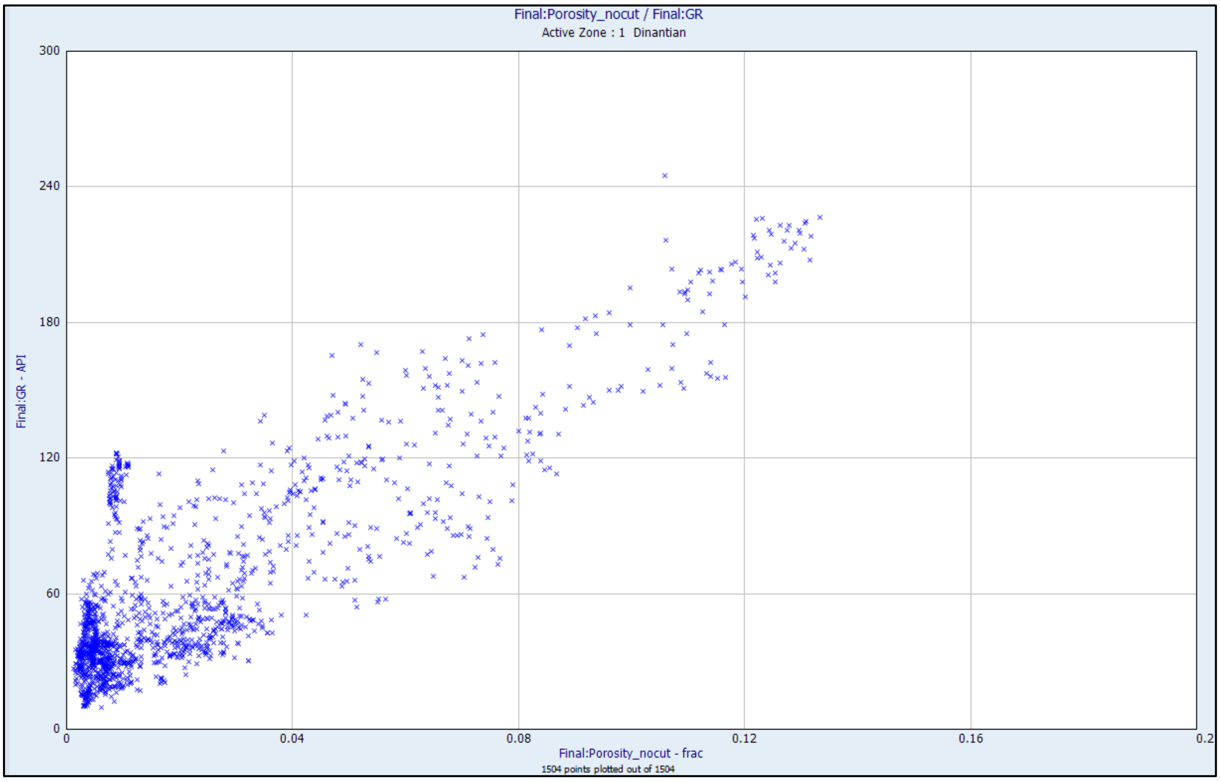


Figure 3. GR versus uncut porosity.

A clay indicator based on the GR has been calculated (clean GR=15 and 100 % shale at 260 API):

Clay Indicator = - 0.06122 + 0.004082*GR

For a clay indicator above 0.1 the porosity is set to 0 because high clay content will result in higher total porosity, but this porosity will have no permeability and should therefore not be included.

Based on the description of the lithology, there are sandy/shaly Limestones but no Dolomite in the Dinantian in WSK-01. The Limestone proportion has been calculated from the matrix slowness derived from the sonic-neutron cross plot, limited to the interval 165 (Limestone) to 185 us/m (Sandstone). The reason for applying a higher slowness value for the Limestone than the normal of 160 us/ft is that there is clay in many of the Limestone resulting in a bit slower matrix for the Limestone and that the sandstone proportion should not be unrealistically high. The resulting equation for Limestone corrected for the clay content (Clay_Indicator):

Limestone = (9.25 - 0.05*Dtma) * (1 – Clay Indicator)

Sandstone = 1 – (Limestone + Clay Indicator)

The equations above for limestone content, even after using a higher slowness than normal for Limestone, will probably overestimate the sand/silt proportion in some layers of the rock. However, this lithology representation is mostly confirming the lithology description from the composite log.

Result

The result of the evaluation can be seen in the log evaluation plot. In the evaluation track 10 is the Clay Indicator, in track 11 the porosity without any cut offs and in track 12 the porosity with a Clay Indicator cut off of 0.1. In track 13 is the calculated lithology described in this report displayed and in the last track, 14, the interpreted lithology from cuttings is shown.

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
218,0	96,93	0,445	0,008	0,058	0,80	1,00	0,00
218,0	23,16	0,106	0,018	0,071	0,41	0,51	0,01
218,0	8,38	0,038	0,024	0,081	0,20	0,25	0,02
218,0	0,61	0,003	0,031	0,078	0,02	0,03	0,03
218,0	0,00	0,000			0,00	0,00	0,04

The net, net/gross and the product of average porosity and net decreases rapidly with increasing porosity cut off and there is no porosity exceeding 4 % in this well. 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 4 below.

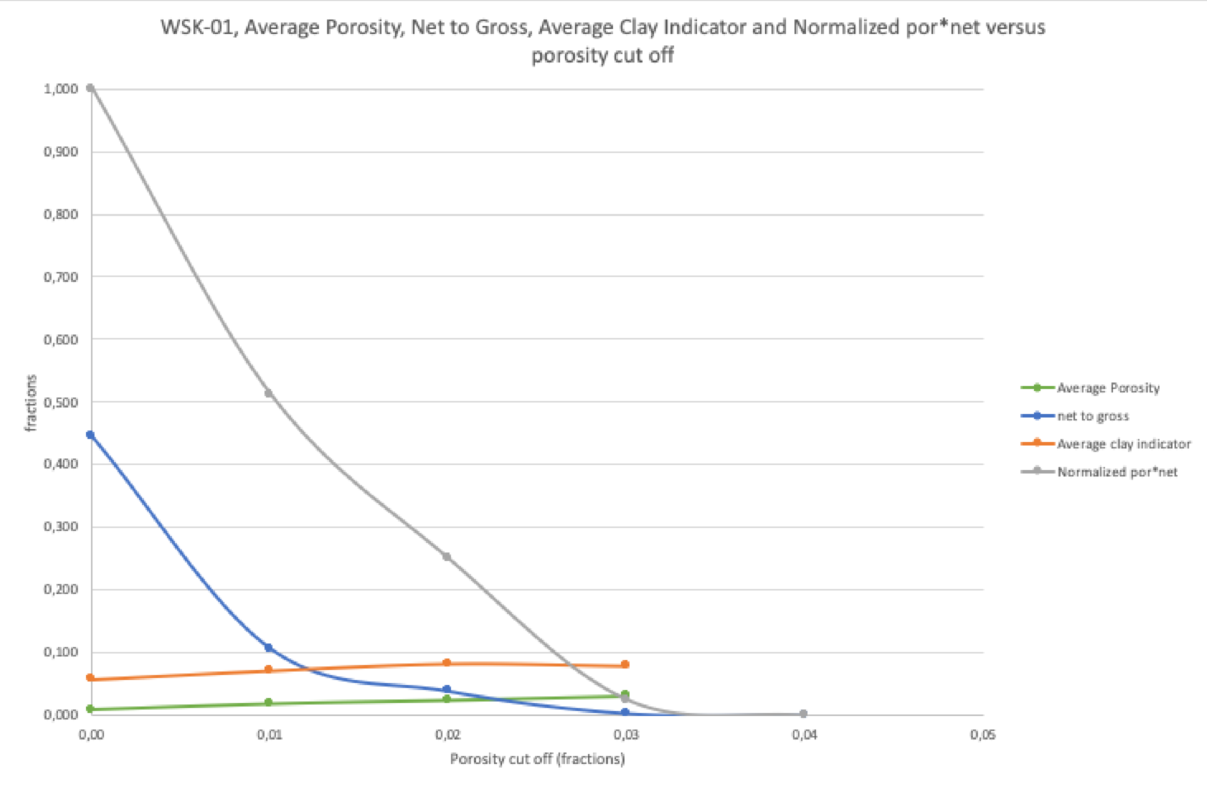


Figure 4. Average porosity, net-to-gross, clay indicator and normalized porosity*net thickness for increasing porosity cut-off

The graph illustrates the rapid decrease in net and the product of average porosity and net declines with increasing porosity cut-off. The production of average porosity and net declines slower due to the increase in average porosity with increasing porosity cut-off.

The average porosity with no porosity cut-off is low in this well with a value of 0.8 %. The shale cut off is relatively stable in this well.

Discussion

Overall the porosity is very low and in many intervals the rock has no porosity. In the uppermost part of the Dinatian, 4275-4300 m, there were a few calculated high porosities. However, based on a good correlation between high calculated porosity and high GR and a clear shale signature on the density-neutron overlay indicate that this is not effective porosity but tight rock and has therefore been cut out. The cleaner, lower GR, intervals have low to very low porosity 0.5-2 %.

In the interval 4300-4350 m there is a layered sequence with calcareous mudstones and limestones and muddy limestones with some silt-sand. The limestones have very low porosity, below 1 %, the muddy limestones slightly higher and the mudstones up to 3-4 % but none of the higher porosity is effective and have been cut out.

The interval 4350-4408 m consist of muddy limestones and some limestone, all with very low porosity, generally below 1.5 %.

A short interval 4408-4415 m is very shaly with a considerable amount of sand towards the base. Due to the high clay content the porosity has been cut out.

The intervals 4415-4430.5 m and 4445-4461 m (base Dinantian at 4460 m) consist of mudstones (calcareous) and limestones that according to the lithology log are sandy, something that is difficult to confirm from the logs. The limestones have very low porosity, less than 1 %. Porosity in the mudstones is a bit higher, up to 5 %, but these have been cut out due to no effective porosity.

The interval 4430.5-4445 m is the shale layer named Ponte d'Arcole and has a clearly anomalous when comparing to more shaly layers in the upper part of the Dinantian. The log expression of this shale is more similar to those in the Devonian.

Core data

The Dinantian was cored in two intervals, 4232-4241 (100 % recovery) and 4433-4441.5 m (100 % recovery). Only the lower core in the shale has been analyzed for porosity and grain density.

Flow potential

Tests

1 test was performed in the Dinantian with the following description on the composite log:

7/2/1978 4299-4322.0 m (301 shots). Acidized with 16.7 m3 acetic acid (MSA). No influx or pressures observed during test.

The interval perforated, 4299-4322 m, is a very tight Limestone with relatively low clay content and would not be expected to flow. The test confirms this.

In the test report, a reservoir pressure of 475-520 bar at 4300 m NAP is quoted. However, the mud density during drilling of this section varied from 1150-1200 kg/m3 and with the lower density the hydrostatic pressure of the mud would only be 490 bar. The conclusion is that the formation pressure could be 475-490 bar but not much higher. The reason is that there would probably have been some influx or other drilling issues, something that is not seen from the reports or from the hole condition when logging. It is also quite possible that the formation pressure is lower than the quoted pressure because there are no pressure measurements made. The conclusion is therefore that the pressure is most likely in the range 460-490 bar, where the lower pressure would correspond to sea water density down to 3000 m and the remaining with a salt saturated brine of 1190 kg/m3. This may also be on the low side. However, it can be concluded that the well were not likely to be overpressured and if it were, the overpressure would have been very mild.

Wireline formation tester

No wireline formation tester was run in this well.

Formation temperature

Table showing the maximum temperatures from logging runs at TD (5009.5 m)

Log	Depth	Log date	Time since circ.	Max Temp
	(m)		(hrs)	(deg C)
GR/FDC/CNL	4995	18/12/1977	11	164
GR/DLL	4995	18/12/1977	14	167
GR/BHC	4995	19/12/1977	16	171

Horner extrapolation of the measured temperatures result in a formation temperature of 186 deg C at 4995 m

Table showing the maximum temperatures from logging runs at 12 ¼" bottom

Log	Depth	Log date	Time since circ.	Max Temp
	(m)		(hrs)	(deg C)
GR/FDC/CNL	3440	17/8/1977	16	117
GR/BHC	3440	17/8/1977	24	116
GR/DLL/MSFL	3440	17/8/1977	32	120

Horner extrapolation of all the data result in a formation temperature of 121 deg C. Because the temperature measured on run 2 is a degree lower than on the first run, an alternative Horner extrapolation of the temperatures on the first and third run result in a formation temperature of 123 deg C and this is judged to be the more reliable formation temperature. This extrapolated formation temperature is probably less reliable than for the other two sets of data.

Table showing the maximum temperatures from logging runs at 3081 m 12 ¼" hole.

Log	Depth	Log date	Time since circ.	Max Temp
	(m)		(hrs)	(deg C)
GR/ISF/BHC	3070	5/8/1977	18	110
GR/FDC/CNL	3070	5/8/1977	27	113

Horner extrapolation result in a formation temperature of 119 deg C.

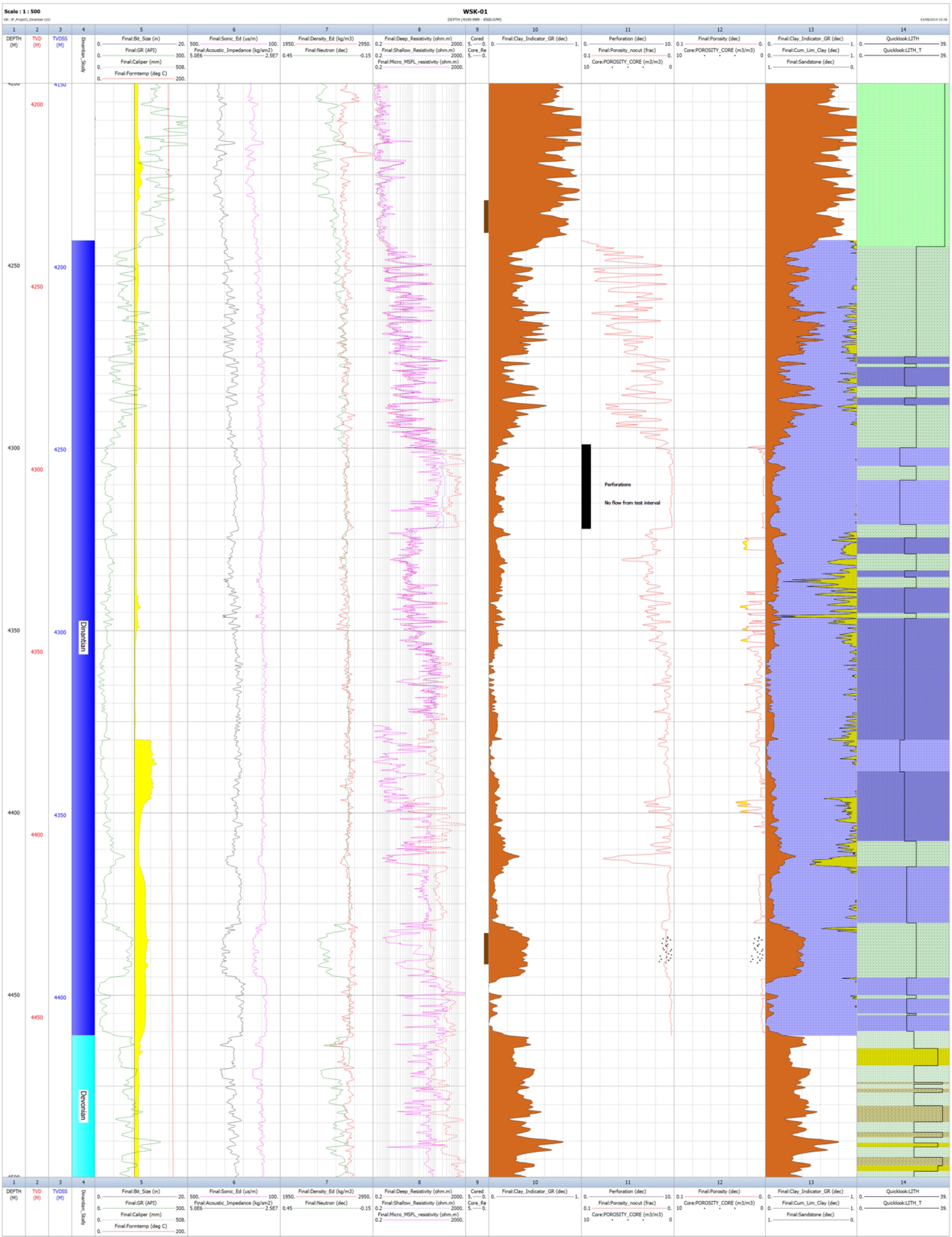
Table of temperature gradients based on the Horner derived formation temperatures using a surface temperature of 10 deg C. Gradients are

Depth	Depth TVDss	Temperature	Temperature gradient	Temperature gradient back to surface
m	m	Deg C	Deg C/m	Deg C/m
7.3 (surface)	-37.3	10		
3070	3021.7	119	0.0356	0.0356
3440	3390.6	123	0.0108	0.0329
4995	4943.9	186	0.0406	0.0353

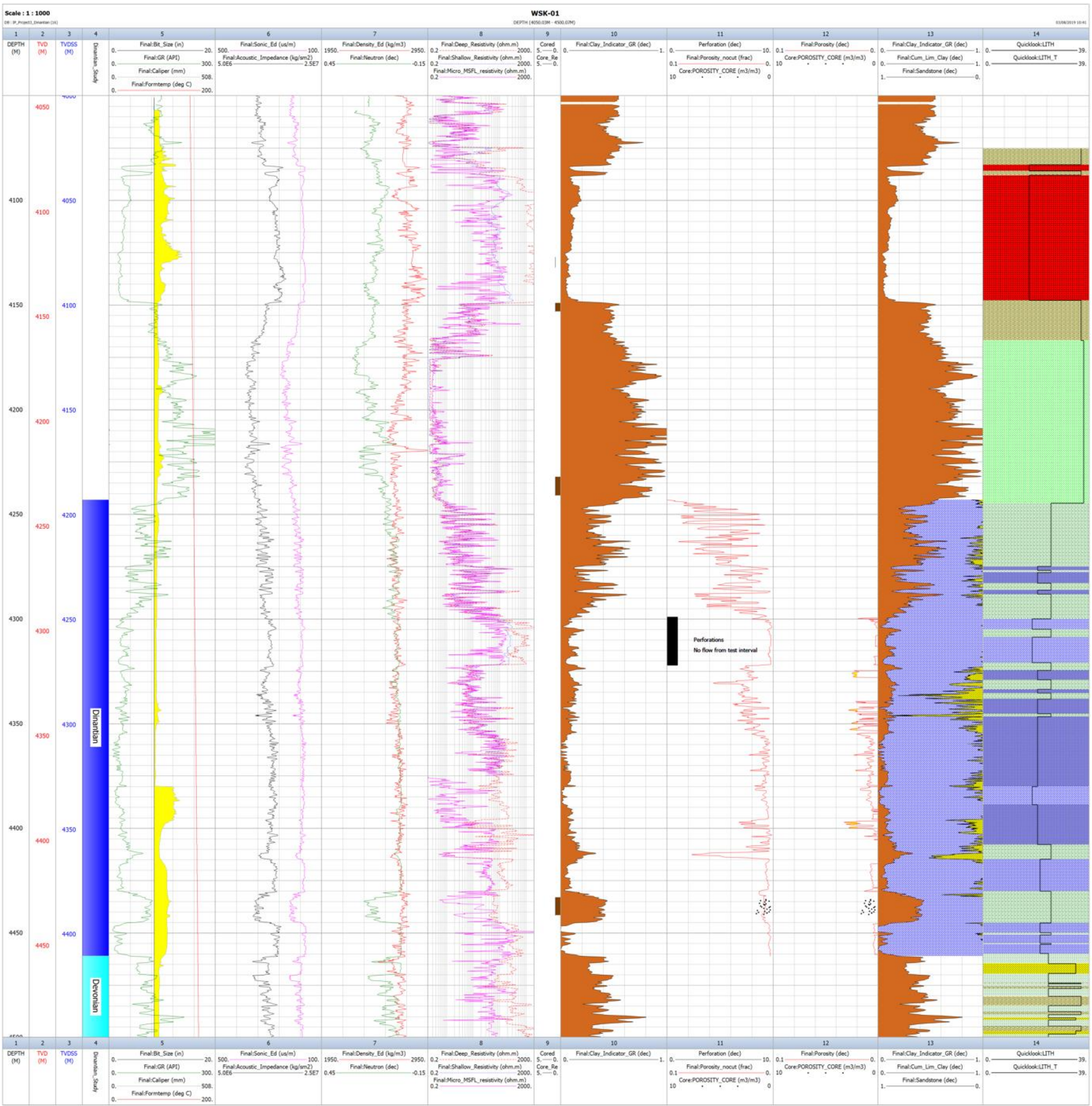
Because the temperature gradient to TD and to 3070 m agrees closely, only the temperature gradient to TD is used for the entire well resulting in the following equation for formation temperature:

Formation Temperature = 11.32 + 0.03533 * TVDss

Evaluation plot



Evaluation plot (including volcanics)



Well Logging Summary WSK-01

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"		GR-FDC	GR-Formation Density Comp	SCHLUMBERGER	EWL	1	1	Main	**Up**	03-JUN-1977	547.5	1317.7	
17 1/2"		GR only	Gamma Ray	SCHLUMBERGER	EWL	1	2	Main	**Up**	03-JUN-1977	547.5	surface	**in casing**
17 1/2"		SL	Sonic Borehole Comp	SCHLUMBERGER	EWL	1	3	Main	**Up**	03-JUN-1977	547.5	1315.1	
17 1/2"		LL	Dual Laterolog Rxo	SCHLUMBERGER	EWL	1	4	Main	**Up**	03-JUN-1977	547.5	1312.7	
17 1/2"		HDT	Dip-Log	SCHLUMBERGER	EWL	1	5	Main	**Up**	03-JUN-1977	547.5	1317.6	
12 1/4"		GR-FDC	GR-Formation Density Comp	SCHLUMBERGER	EWL	2	6	Main	**Up**	17-JULY-1977	1316	2443	
12 1/4"		LL	Dual Laterolog Rxo	SCHLUMBERGER	EWL	2	7	Main	**Up**	17-JULY-1977	1316	2441.5	
12 1/4"		BGT	Borehole Geometry tool Dev AZ	SCHLUMBERGER	EWL	2	8	Main	**Up**	17-JULY-1977	1316	2440.0	
12 1/4"		LL	Dual Laterolog Rxo	SCHLUMBERGER	EWL	2	9	Main	**Up**	05-AUG-1977	2300	3081.4	
12 1/4"		ISF-SL	IND-SON	SCHLUMBERGER	EWL	2	10	Main	**Up**	05-AUG-1977	1317.3	3081.5	
12 1/4"		GR-FDC	GR-Formation Density Comp	SCHLUMBERGER	EWL	2	11	Main	**Up**	05-AUG-1977	2294	3082.2	
12 1/4"		GR-FDC	GR-Formation Density Comp	SCHLUMBERGER	EWL	2	12	Main	**Up**	05-AUG-1977	1317	2356.0	rerun of 17-7-77
12 1/4"		HDT	Dip-Log	SCHLUMBERGER	EWL	2	13	Main	**Up**	16-AUG-1977	1316	3451.3	
12 1/4"		GR-FDC	GR-Formation Density Comp	SCHLUMBERGER	EWL	2	14	Main	**Up**	17-AUG-1977	3050	3451.5	
12 1/4"		GR-LL	Dual Laterolog Rxo	SCHLUMBERGER	EWL	2	15	Main	**Up**	17-AUG-1977	3050	3451.0	
12 1/4"		GR-SLC	Sonic Borehole Comp	SCHLUMBERGER	EWL	2	16	Main	**Up**	17-AUG-1977	3050	3445.0	
8 1/2"		GR-FDC	GR-Formation Density Comp	SCHLUMBERGER	EWL	3	17	Main	**Up**	14-SEP-1977	2358	3442.5	
8 1/2"		SL	Sonic Borehole Comp	SCHLUMBERGER	EWL	3	18	Main	**Up**	14-SEP-1977	3447.5	4056.5	
8 1/2"		GR-LL	Dual Laterolog Rxo	SCHLUMBERGER	EWL	3	19	Main	**Up**	07-OCT-1977	3447.5	4051.5	
8 1/2"		GR-SLC	Sonic Borehole Comp	SCHLUMBERGER	EWL	3	20	Main	**Up**	07-OCT-1977	4050	4380.5	
8 1/2"		GR-FDC	GR-Formation Density Comp	SCHLUMBERGER	EWL	3	21	Main	**Up**	07-OCT-1977	4000	4378.5	
8 1/2"		GR-FDC	GR-Formation Density Comp	SCHLUMBERGER	EWL	3	22	Main	**Up**	18-NOV-1977	4054	4380.4	
8 1/2"		HDT	GR-Dip Log	SCHLUMBERGER	EWL	3	23	Main	**Up**	18-NOV-1977	4380	4716.0	
8 1/2"		LL	Dual Laterolog Rxo	SCHLUMBERGER	EWL	3	24	Main	**Up**	18-NOV-1977	4380	4714.0	
8 1/2"		SL	Sonic Borehole Comp	SCHLUMBERGER	EWL	3	25	Main	**Up**	18-NOV-1977	4380	4713.5	
8 1/2"		FDC	GR-Formation Density Comp	SCHLUMBERGER	EWL	3	26	Main	**Up**	18-DEC-1977	4500	5009.5	
8 1/2"		LL	Dual Laterolog Rxo	SCHLUMBERGER	EWL	3	27	Main	**Up**	18-DEC-1977	4500	5006.0	
8 1/2"		SL	Sonic Borehole Comp	SCHLUMBERGER	EWL	3	28	Main	**Up**	18-DEC-1977	4500	5006.5	
8 1/2"		BGT	4 arm Cal	SCHLUMBERGER	EWL	3	29	Main	**Up**	18-DEC-1977	3447.5	5000.0	

Appendix: Horner plots

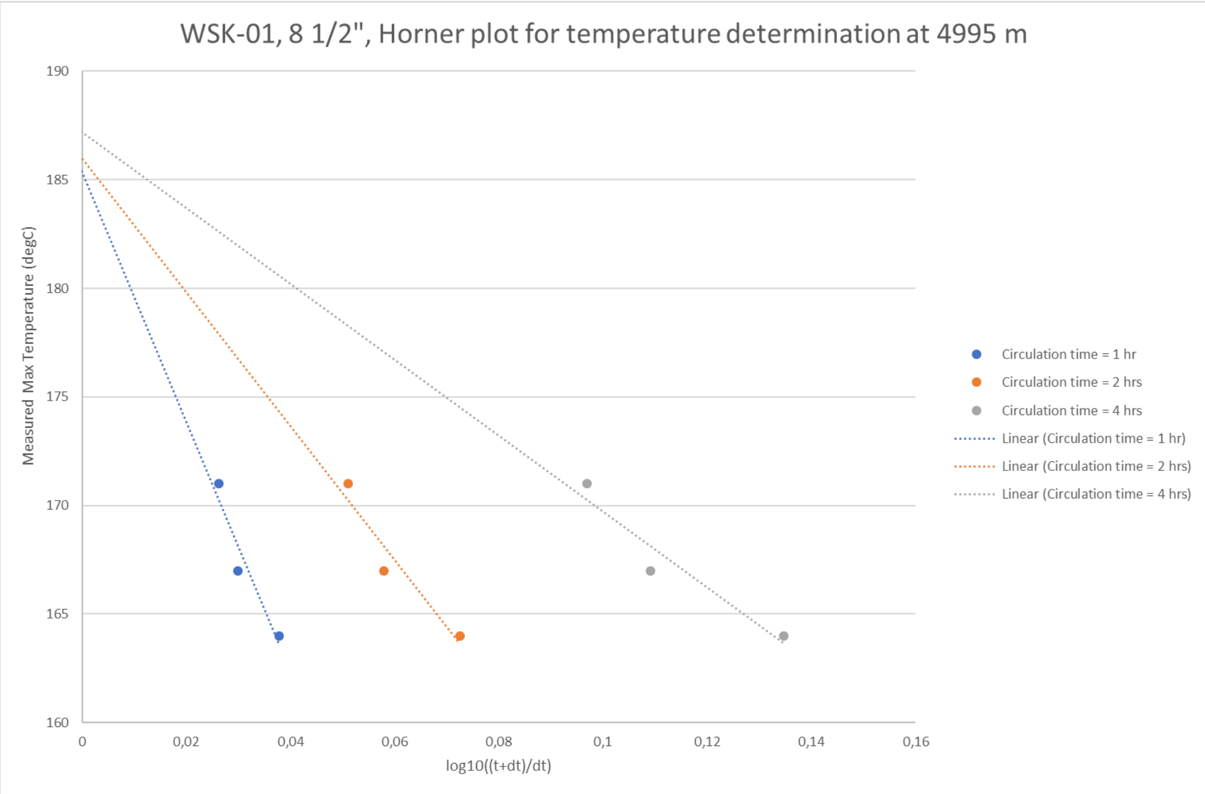


Figure 1. Horner plot at 4995m

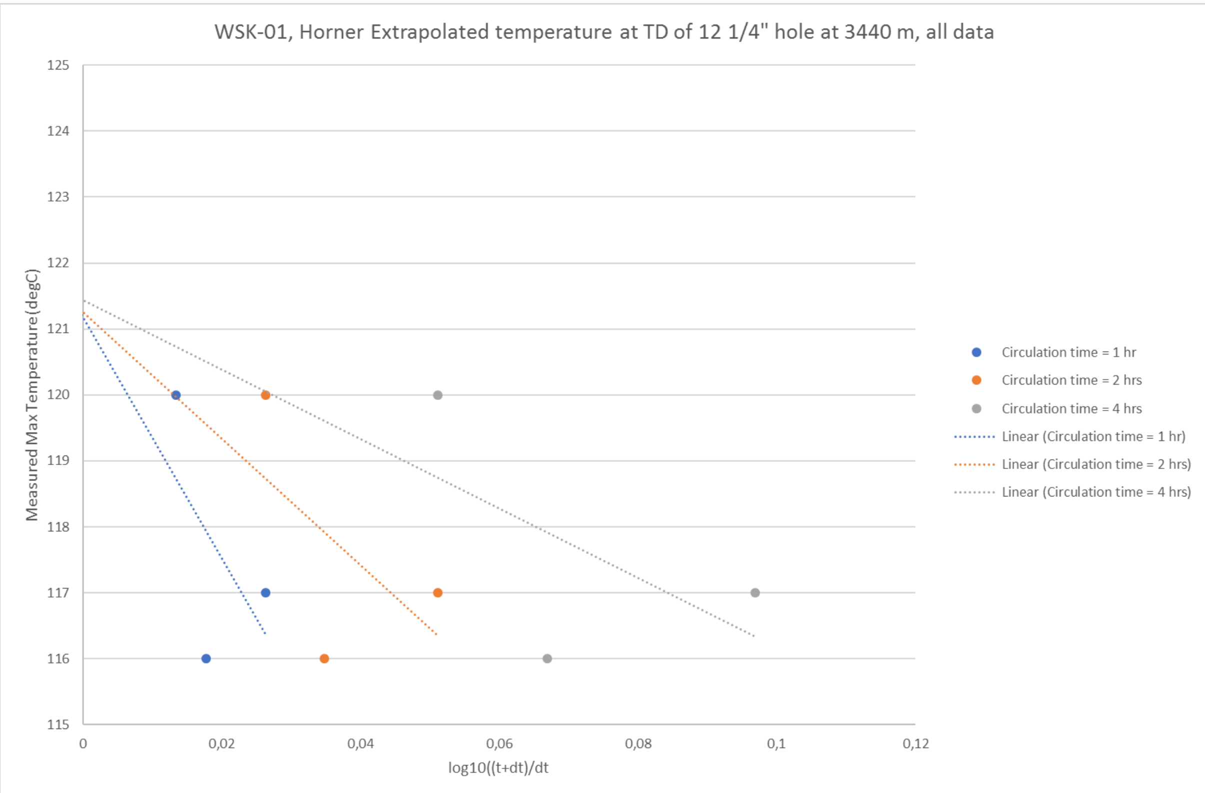


Figure 2. Horner plot at 3440m

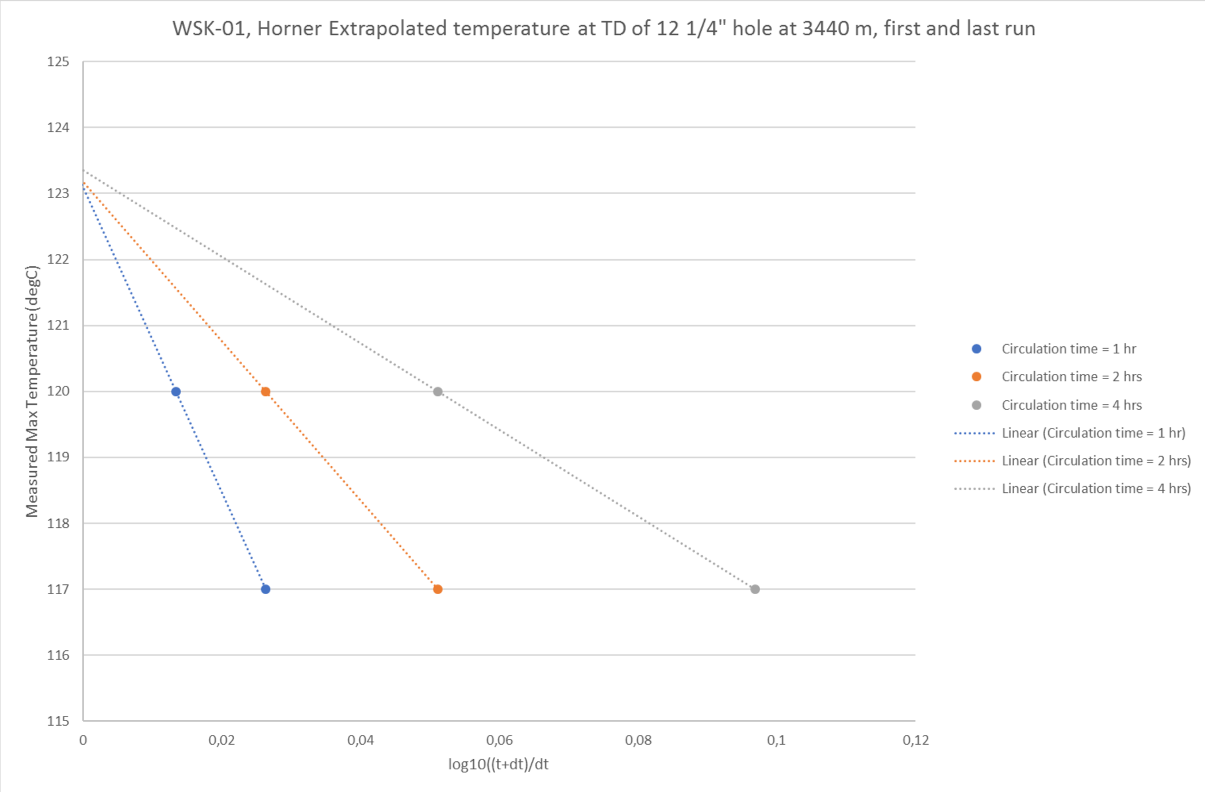


Figure 3. Horner plot at 3440m

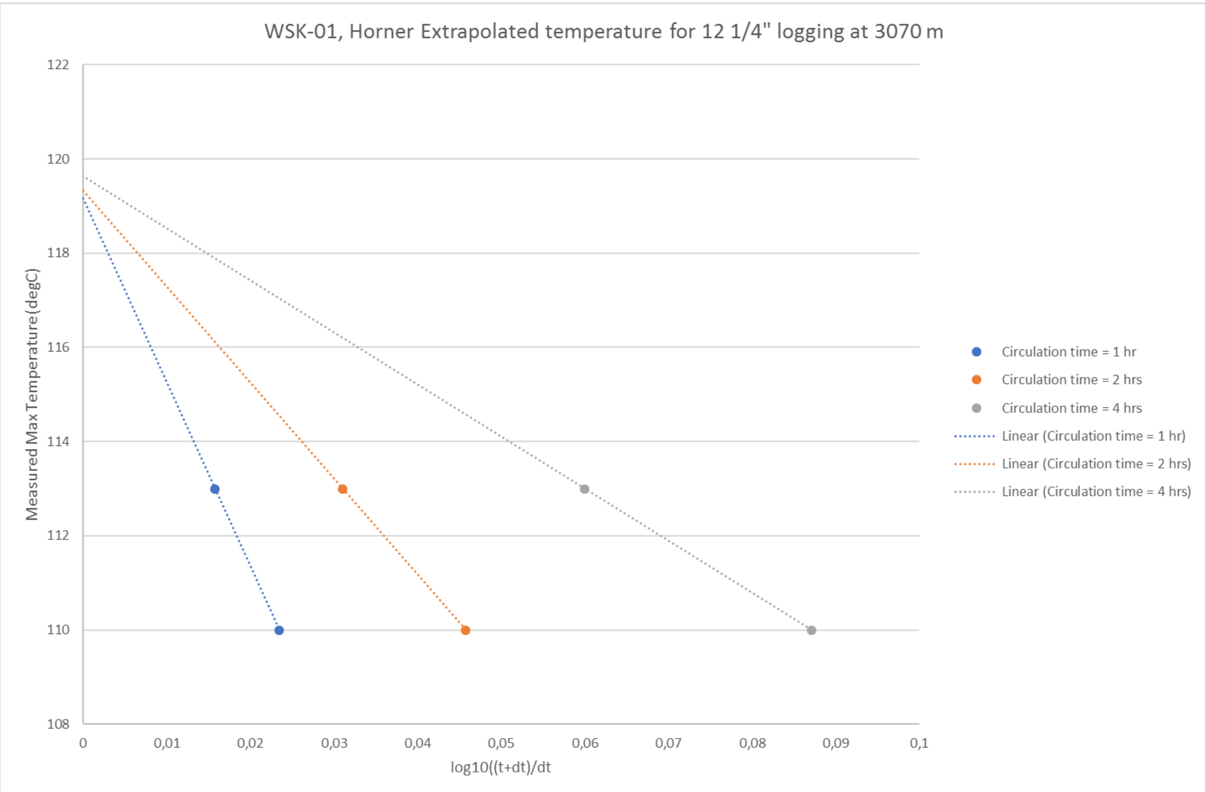


Figure 4. Horner plot at 3070m

Daalsesingel 1
3511 SV Utrecht
scan@ebn.nl
www.scanaardwarmte.nl

Onderzoek in de ondergrond voor aardwarmte

www.scanaardwarmte.nl