Well Test Analysis TNT-GT-01P

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1 Executive Summary

Well TNT-GT-01P was production tested from 19th of April 10:49 till 20th of April 00:30, followed by a shut-in period of 11 hours. The production rates varied between 140 and 270m3/hr. Cumulative water produced was about 3000m^3.

The main conclusions:

- Transmissivity was found to be 48.7 Darcy-meter
- Under assumption of a net reservoir thickness of 166m an average permeability of 293 milli-Darcy is derived
- Minimum reservoir temperature is 85.4°C
- Transient PI after 14 hours of production is 28m3/hr/bar
- A reservoir skin (S0) of -1.5 is found

2 Well test results

Flow sequence	Duration	Flow rate	Final P @ ESP	PI @ ESP
	[hr]	*[$m^3 \cdot hr^{-1}$]*	*[Barg]*	*[m3/hr/bar]*
Cleanout 1	1	*143*	72	16
Cleanout 2	2.5	*261*	71	28
Production 1	2	*163*	76	34
Production 2	2	*217*	74	31
Production 3	6	*250*	72	28

Table 1 Flow sequences of test

Type of model	Model used	Note
Wellbore storage	Changing	ESP typically shows a changing wellbore effect.
Well model	Vertical + rate dependent skin	
Reservoir model	Homogeneous	
Boundary model	Infinite	Due to inaccuracy of sensor and uncertainty in temperature correction far field response is highly uncertain

Table 2 Description of analytical models used

Parameter		value	Unit	Note
Permeability thickness	$k{\cdot}h$	48.7	D·m	
Assumed net thickness	h_{nett}	166	m TV	
Permeability	k_h	293	mD	
Static skin	S_0	-1.5	-	
Rate dependent skin	S_q	0.00906	$(m^3hr^{-1})^{-1}$	
Flow barrier at	L_{bar}	N.A.	m	Data not accurate enough for reliable determination of late-time response
Formation pressure	P_{res}	235.3	bara	@ reference depth: 2296m TVGL
Minimum formation temperature	T_{res}	85.4	°C	Highest measured temperature during test

Table 3 Well test analysis results

3 Introduction

In March 2020 drilling of the TNT-GT-01P well commenced. This well is designed to be the the production well of a geothermal doublet owned by Duurzaam Voorne Holding and operated by Hydreco Geomec.

Water will be circulated through the main Buntsandstein. This is a thick sandstone succession of Triassic age. MWD and open-hole measurements showed that stratigraphic sequence of the sandstone succession is around 202 meters thick. The lower part of the reservoir is shown to be tight and is therefore not completed.

The well consists of two casing strings (see Appendix A). The reservoir is perforated underbalanced. The lower part of the reservoir was not perforated. After perforating, the well stabalized with a static water level several tens of meters below ground level. The reservoir pressures gradient is therefore equal to the local hydrostatic gradient.

After perforating the well, a production test was performed to assess the productivity of the well and to derive the hydraulic reservoir characteristics. The test was performed with an ESP as artificial lift method. Testing commenced the 19th of April 10:49 and the well was shut in for a 10.5 hour build-up period on the 20th of April 00:30.

This document contains the analysis of the welltest. The goal of the analysis is to give a value for the average reservoir parameters. These parameters are derived with means of a pressure transient analysis. For this analysis the software package Kappa Sapphir is used.

4 Input parameters

Parameter		value	Unit	Note
Reservoir Properties (see Appendix B)				
Top Reservoir	Z_{topres}	2515	m AHGL	Top Hardegsen Fm (Drillers depth)
		2313	m TVGL	
Bottom Reservoir	Z_{botres}	2804	m AHGL	Top Rogenstein Fm (Drillers depth)
		2529	m TVGL	
Gross True Stratigraphic thickness	*TST*	202	m	Main Buntsandstein = Top Hardegsen to Top Rogenstein
Net over gross	*N/G*	82	%	Average for Main Buntsandstein Based on cutoff of VCL<35% and PHI_{eff}>8% *(Average for perforated interval is 86.8%)*
Porosity	φ	14.2	%	Average PHI_{eff} for <u>net</u> sand interval in Main Buntsandstein *(Average for net sands in perforated interval is 14.9%)*
Pore compressibility	c_f	$4.35*10^{-10}$	Pa^{-1}	Estimated
Well Properties (see Appendix A)				
Well Code	TNT-GT-01P			
Surface Coordinates	*X*	68783	m (RD)	
	Y	435272	m (RD)	
Well radius @ reservoir	r_w	6.125	Inch	Assumed hole size, based on bit size
inclination @ reservoir	α	42	°	Weighted average over perforated section
Top perforations		2518	m AHGL	2526m AHBRT
		2314	m TVGL	Derived from directional survey
Bottom perforations		2747	m AHGL	2755m AHBRT
		2485	m TVGL	Derived from directional survey
ESP Gauge Depth	Z_{ESP}	837	m AHGL	
		837	m TVGL	
Deep Gauge Depth	Z_{dg}	2494	m AHGL	
		2296	m TVGL	
Brine Properties				
Reference temperature	*T*	85	°C	Highest measured temperature during test.
Salinity	*Sal*	130	$g \cdot L^{-1}$	Assumed based on PVT from BRI-GT-01.
Compressibility	c_w	$3.54*10^{-10}$	Pa^{-1}	Derived from salinity and temperature
Viscosity @ ref-T	μ	0.44	$mPa \cdot s^{-1}$	Van Wingen & Frick

5 Data processing

5.1 Brine flow rate

The brine flow rate was measured with two flow meters. Meters where placed behind separator. Both meters gave good sensor readings. Flowmeter one was taken to be leading.

The sampling rate was every second for flow rate.

Measured brine flow rates were simplified to flow-rate steps and correlated to the pressure data. Simplified brine flow rates are given in Table 4.

The following rates where used for analysis

Delta time [hr]	Flow rate [m^3/hr]
1.05	143
0.23	211
2.25	261
2.02	163
2.10	217
5.98	250
10.5	0

Table 4 Simplified flow rate steps derived from measured brine flow rates

5.2 Pressure readings

Pressure was measured at ESP level. The ESP gauge has provided sensor readings for the entire welltest duration. The pressure sampling rate was every 1 minute.

As a backup, a second downhole gauge was installed. This gauge will only be retrieved after the circulation test that is planned for June. Therefore, the current analysis has been performed based on the ESP gauge data.

5.3 Correction for water column cooling

The ESP gauge data of the welltest of TNT-GT-01P have been corrected for water cooling. The correlation between ESP and reservoir pressure that was derived from the ESP and deep-gauge data of the BRI-GT-01P well test analysis has been used.

The correlation is:

$$\Delta P = CDC \cdot L \cdot (1062.06 + 0.4718 \cdot \Delta T - 0.003574 * \Delta T^2)$$

With:

ΔP = Pressure correction in bar
CDC = Constant (=$9.8063*10^{-10}$)
L = Vertical depth difference between datum depth and ESP depth in meters (1478m)
ΔT = The difference between the maximum and current ESP temperature in °C

The equation above has been used to correct the ESP gauge pressures in TNT-GT-01P to a datum depth (top perforations) of 2518mTVGL using a maximum reservoir temperature of 86°C and a vertical depth difference of 1478 m TV.

It must be noted that an uncertainty rests on this correlation. The temperature profile along the borehole is heavily influenced by the isolation values of the casing and circumjacent cement. The GRE-lined casing is known to have much higher isolation values than bare carbon steel casing. However, since no correction values for this GRE-lined casing well design is available, the correlation of BRI-GT-01 has been used (carbon steel casing). This most likely has resulted in an overestimation of the temperature related ΔP correction. The effect of this uncertainty adds a relatively big uncertainty to the analysis because of the small pressure responses related to the very good transmissivity/productivity of the well. To illustrate the effect of the temperature correction both corrected and uncorrected build-up pressures have been plotted in a Horner plot. This can be found in Appendix E.

6 Analysis

6.1 Quick look data

As a first step, the data during the well test was plotted as an overview (Figure 1). To get a quick feeling for the productivity of the well, the productivity at ESP level is calculated (*$Q/(P_{in,stat}-P_{in,dyn})$*). This is depicted as the dark blue curve in Figure 1. The data shows that the well significantly cleans up in the in the first cleanout stage (see also water samples in Appendix D). The transient PI increases from 15 to almost 33 m3/hr/bar. The final transient PI settles around 29m3/hr/bar.

Figure 1 Welltest TNT-GT-01P data - Quick look

6.2 Pressure transient analysis

Pressure transient analysis was done with help of the Kappa Saphir software package. First the build-up data was matched with an analytical solution using a log-log plot (Argarwal plot) and the semi-log plot (Horner plot). Secondly the analytical model is fitted to the full welltest data excluding the cleanout period.

A vertical well model has been used, based on the assumption that the flow in the reservoir at some distance from the well will be horizontal, as the vertical permeability is normally lower than the horizontal permeability in sandstone. The matched-model response for short times can be expected to deviate somewhat from the observed pressures. But these early build-up pressures are heavily influenced by the wellbore effects.

For the early-time wellbore effect, a changing wellbore storage model has been used. Build-ups after shutting-down an ESP are best modeled with this type of models. This is believed to be related with a.o. the falling water in the tubing, the rising water in the annulus, and the latent heat of the ESP motor.

For the reservoir, a homogenous model is used. In the build-up data no clear signs are visible that a more complex model is necessary to explain the mid-time pressure response.

For the reservoir boundaries an infinite model has been used.

As a result the historical data with fitted analytical solution, log-log plot, and semi-log plot are depicted in Figure 2, Figure 3, and Figure 4 respectively. Historical plot, semi-log and log-log plot show a good match between data and the analytical solution However, in the late-time the match is less good. This could be improved by using a different boundary model. Due to uncertainty in the temperature correction, this has not been done, but will be done late when the deep-gauge data will be retrieved.

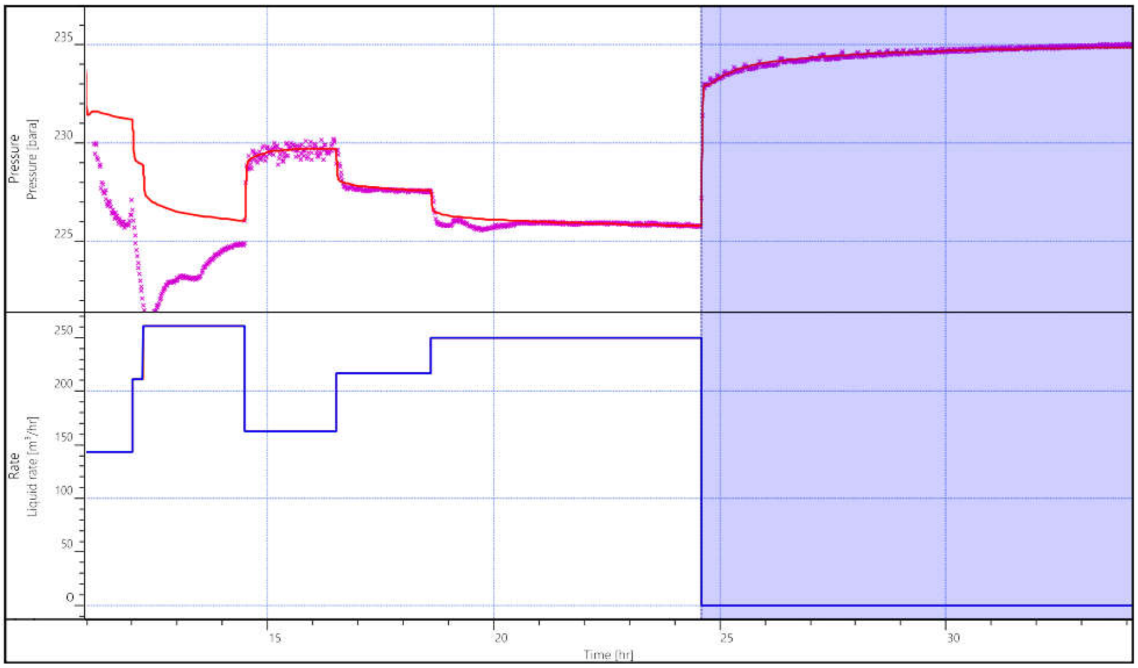


Figure 2 Well test data and matched model. In the blue shaded area, the build-up period that has been used to produce the log-log and semi-log plots. The red line represents the analytical solution and the pink dots represent the pressure data points.

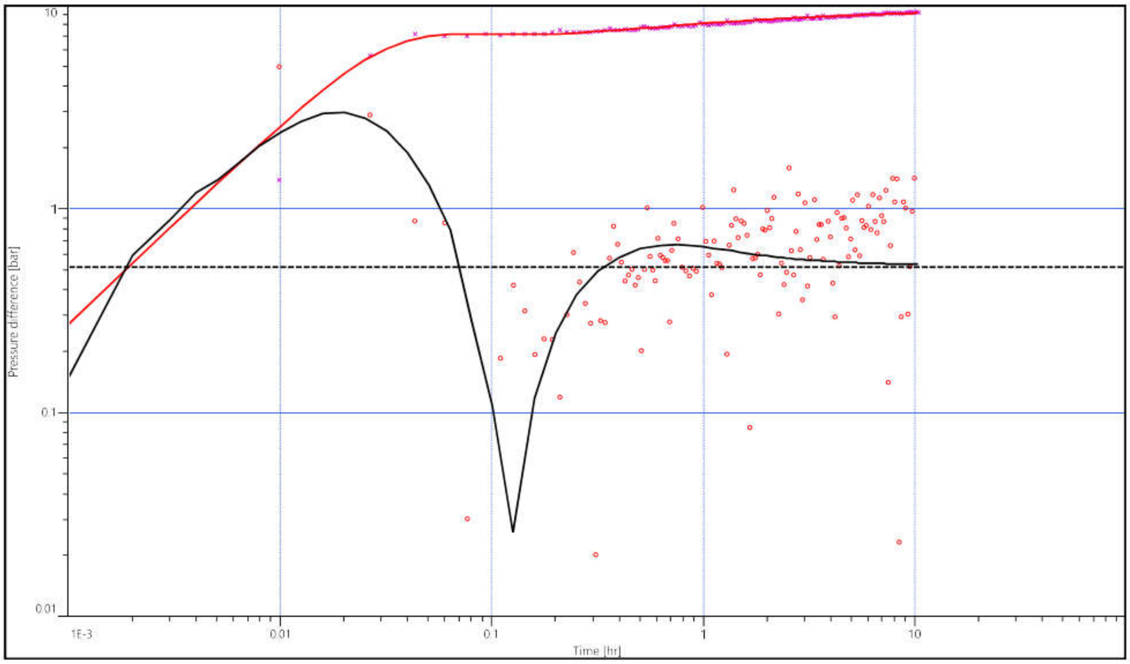


Figure 3 Loglog plot. The red and black line are the pressure and the pressure derivative, respectively. The pink dots are the data points and the red dots represent the corresponding numerical derivative.

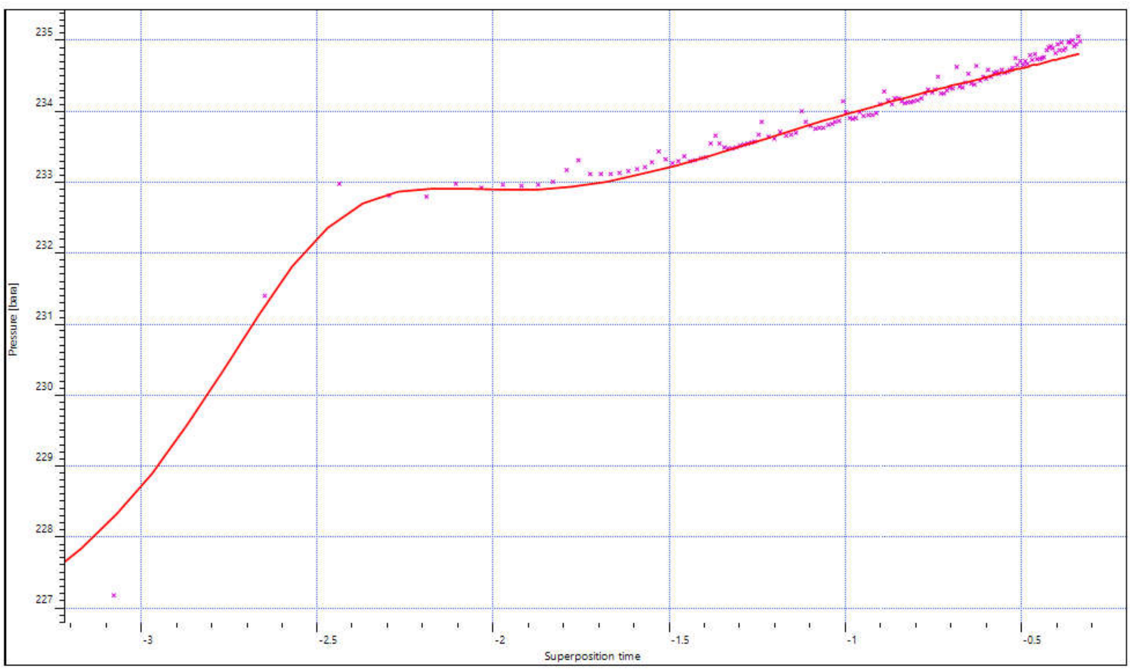


Figure 4 Semi-log plot (Horner plot) The red line represents the analytical solution and the pink dots represent the pressure data points.

7 Conclusions

- Data quality of ESP pressure gauge was adequate for analysis
- The well cleans up fast during the first 4 hours. Transient PI @ ESP is almost doubled in this time from 15 – 33m3/hr.
- Uncertainty in temperature correction makes late-time analysis unreliable

- Transmissivity was found to be 48.7 Darcy-meter
- Under assumption of a net reservoir thickness of 166m an average permeability of 293 milli-Darcy is derived
- Minimum reservoir temperature is 85.4°C
- Transient PI @ ESP after 14 hours of 29m3/hr/bar
- A reservoir skin (S0) of -1.5 is found
- Negative skin shows an improved inflow of fluid into wellbore this can be the result of:
    - Increased contact area due to deviation
    - Increased effective well radius due to clean perforations (theoretical perforation depth is ~14")
    - Uncertainty in analysis due to temperature correction and wellbore effect

Appendix A: Well Schematic

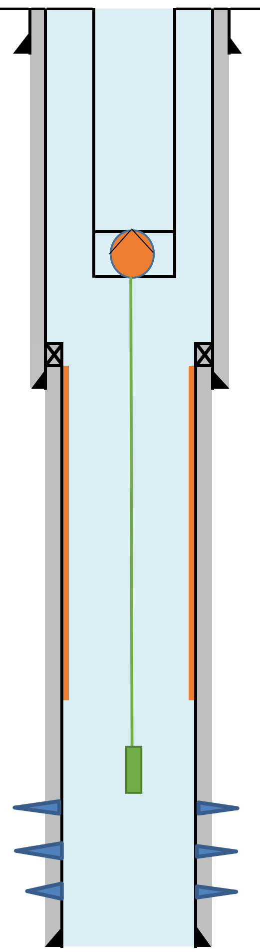
Overview

Sectie	Einddiepte	Einddiepte	Binnen diameter	Ruwheid
	[m AHGL]	[mTVGL]	[Inch]	[mm]
1	837	837	6.276	0.005
2	1209	1198	12.415	0.3
3	2384	2205	8.250	0.04
4	2746	2485	8.681	0.05

Schematic

Production Well, Depths from RT
RT = 8.7m above GL
RT = 8.4m above NAP

Wellhead and Xmastree
TNT-GT-01-P
(Producer)



Nr.	Item Description	Depth m TVD	Depth m AH	Hole ID in	Pipe in	Collar OD in (nom)	Pipe in	Pipe ID in (drift)	Lithology Top TVD
1	24" welded conductor / stove pipe	68	68		24	welded	22	>16	North Sea 8
									Mid NS 370
									Low NS 504
	7", 26#, L80, VAGT	817	817		7.000		6.276	6.151	
	ESP	846	846	Sensor					
	LH 13-3/8" x 9-5/8"	1207	1218						Chalk
2	13-3/8", 68#, K55, BTC	1258	1275	16.000	13.375	14.175	12.415	12.259	1150
									Rijnland 1947
									(Schieland)
									Trias 2201
3	9-5/8", 47# , L80, GRE-Lined VAM								
	X-over 9-5/8" GRE-lined x 9-5/8" CRA	2214	2393		9.625	10.396	**8.250**	**8.125**	
									Rot Fringe 2261
	Memory Gauge	2305	2503						Hardegsen
		2323	2526	*Top Perforations*					2321.5
									Lr Defurth 2396
		2494	2755	*Bottom perforations*					
4									
	9-5/8", 47# , L80, 13Cr, TSH W523	2542	2821	12.250	9.625	9.784	8.681	8.525	Rogenstein
5	9-5/8", 47#, L80, BTC (shoetrack)	2569	2857	12.250	9.625	10.626	8.681	8.525	2538.5

*Not in scale.

Appendix B: Determination of reservoir thickness

The True Stratigraphic Thickness (TST) of a reservoir is defined as the distance between the top and the base of a unit measured perpendicular to the top (Figure B1). The TST reflects the actual thickness of the reservoir. TNT-GT-01 is a deviated well, drilled towards the north-northwest. The reservoir is also dipping towards the northwest.

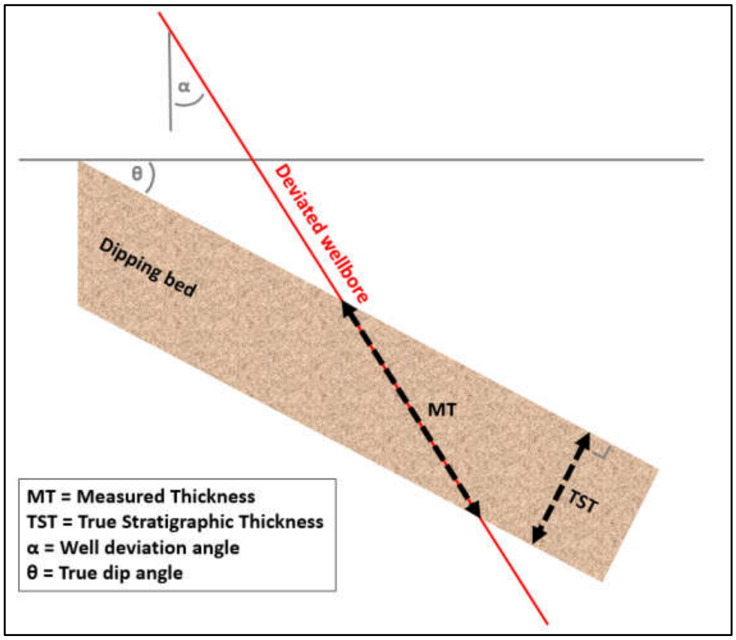


Figure B1 Definition of True Stratigraphic Thickness, shown with respect to a deviated well bore.

TST is calculated using the depth of well tops observed in the well, as well as wellbore orientation and structural dip. The calculation is done using the following formula:

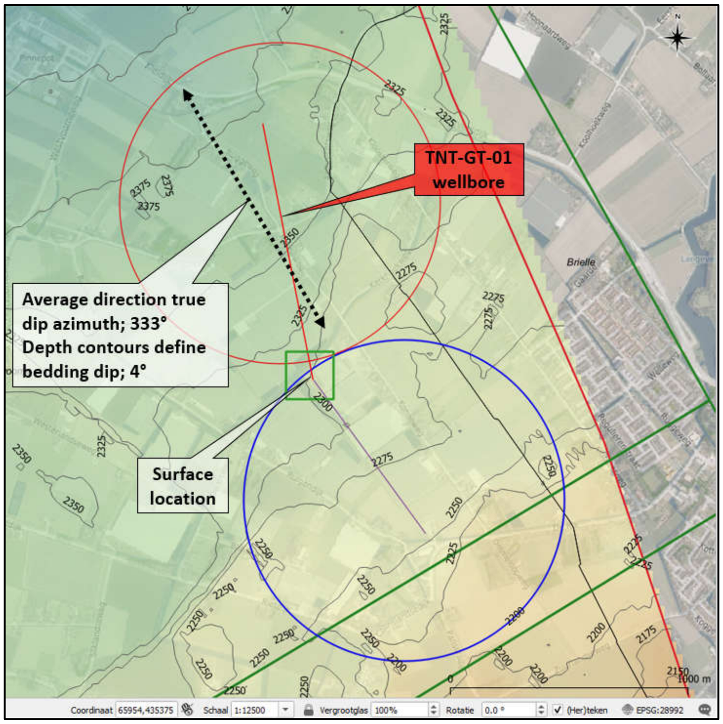
TST = MT * (Cos WD * Cos DIP - Sin WD * Sin DIP * Cos (HAZ - AZM))

Where:

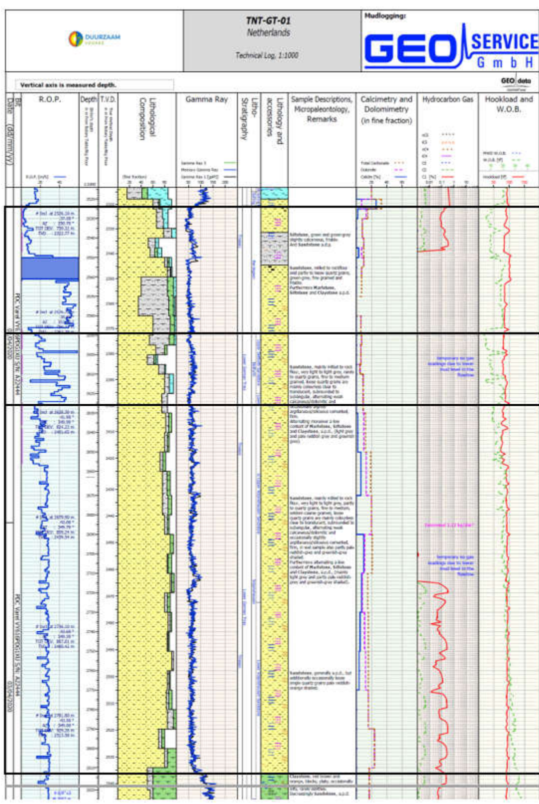
TST	= True Stratigraphic Thickness
MT	= Measured Thickness
WD	= Well deviation angle
DIP	= True dip angle
HAZ	= Azimuth of hole direction relative to true north
AZM	= True dip azimuth

Both the structural dip (4°) and the true dip azimuth (333°) are estimated from the Top Main Buntsandstein depth contour map (Figuur). The measured thickness and average wellbore inclination and azimuth are shown in Figuur B3.

The calculated TST of the Hardegsen Fm is 48m, of the Detfurth Fm 26m and of the Volpriehausen Fm 127m. The total **Main Buntsandstein has a TST of 202m (Gross)**.



Figuur B2 Top Main Buntsandstein depth contour map, bounded by fault (in red). In green: surface location, in red TNT-GT-01 well bore, in blue planned TNT-GT-02 well bore. Circles approximate drainage area. The black dashed arrow indicates average direction of true dip azimuth.



Formations	Perforations	Measured depth below Rotary Table	Measured thickness	Average hole inclination and azimuth
Hardegsen		2523.5m MD-RT	65.5m MT	38.6°, 351°
Detfurth		2589 MD-RT	37m MT	41.3°, 350°
Volpriehausen		2626 MD-RT – 2813 MD-RT	187m MT	43.2°, 349°

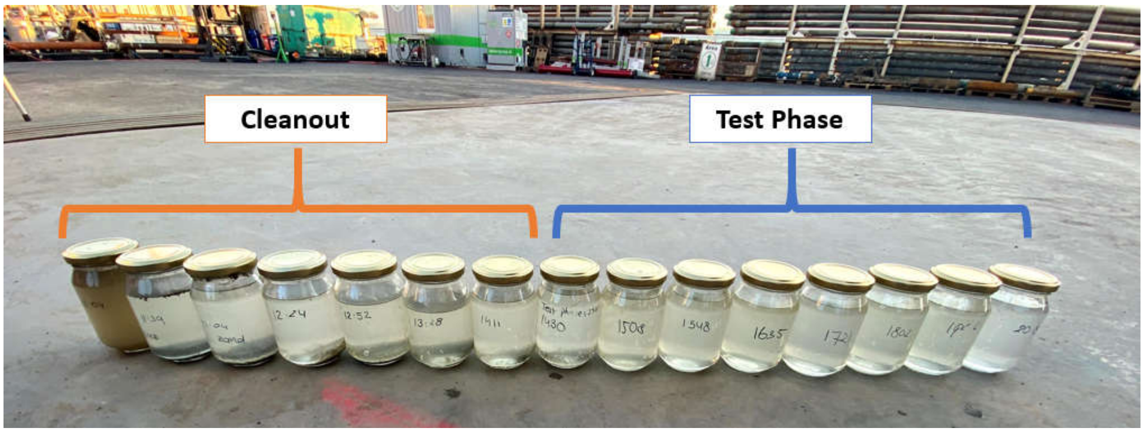
Figuur B3 Litholog, Formation Tops in MD-RT, measured thickness of Hardegsen, Detfurth and Volpriehausen and average well bore inclination and azimuth per formation.

Appendix C: Reference levels

BRT: Below rotary table
GL: Ground level
NAP: Nieuw Amsterdam Peil

BRT– GL = 8.7m
BRT – NAP = 8.4m
GL – NAP = -0.3m (GL is below NAP)

Appendix D: Photos water quality



Appendix E: Horner plot – T-correction

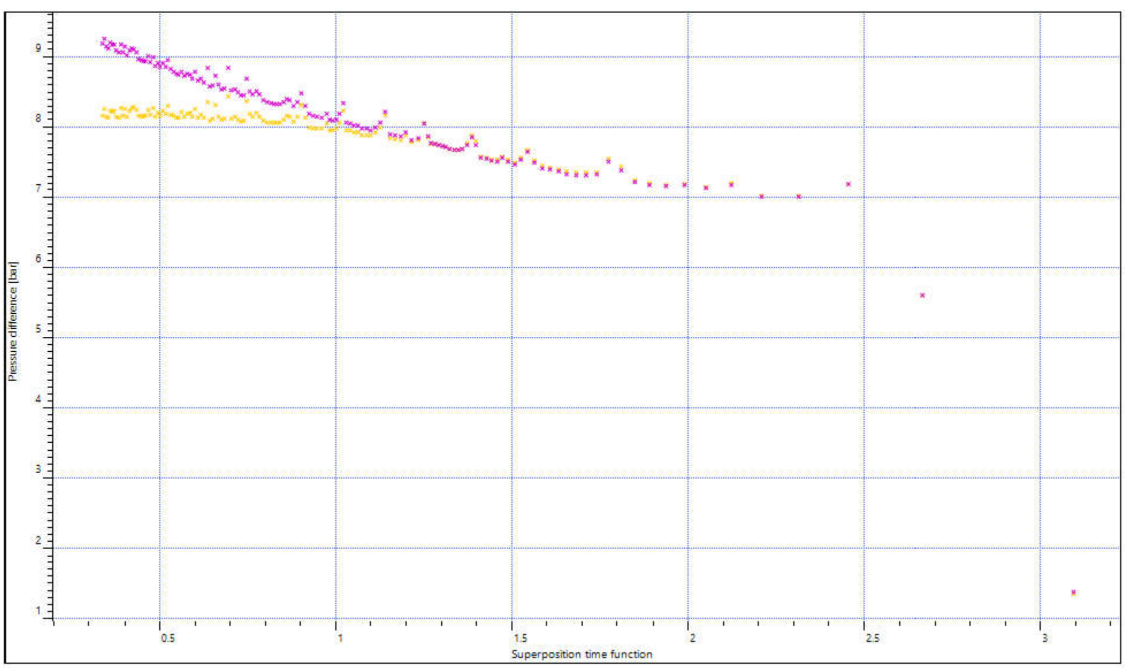


Figure 5 Horner plot illustrating difference due to temperature correction. In yellow the uncorrected ESP data. In purple the corrected data.