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 CAL-GT-01S

Company Name : Californie Wijnen Geothermie BV

Well Name : CAL-GT-01S

Field Name : Californie

Country : The Netherlands

Field Location : Grubbenvorst

Longitude : 06*05’26.525”

Latitude : 51*25’20.257”

Maximum Hole Deviation : 7.56 (deg)@TD

Elevation of Kelly Bushing : 8.04m

Elevation of Ground Level : 0m

Elevation of Derrick Floor : 8.04m

Permanent Datum : Ground level

Elevation of Permanent Datum : 0.0m

Log Measured from : Ground level

Maximum recorded temperature : 89 degC

TD : 2730m

Longitude and Latitude from SLB Log header 30-JUL-2012

Dinantian evaluation in CAL-GT-01S (1596-2303 m MD)

Log quality, edits and depth shifts

Note that the logs over the Dinantian section are from the original hole down to 1751 m and below this depth from the sidetrack.

The logging tools stood up above TD of the hole in both the 12 ¼" hole and in the 8 ½" hole. In the 6" hole the logs reached the TD of the well at 2730 m. The result is large gaps between runs in the different hole sections with the most important for the Dinantian evaluation in the interval 1751-1803.5 m, where only GR through casing is available.

The sonic curve has been spliced together from the dtco in the 8 ½" hole and the final processed dtco in the 6" hole. This curve has gaps where there is no valid sonics, including inside casing and is the curve used in the interpretation.

The 6" logs (Below 1803.5 m) are affected by overpulls in most of the section, although the worst are in the Devonian part. Apart from the tension curve, this is most obvious on the resistivity curves that flatline over longer or shorter sections depending on the size of the overpull. The sonic is also affected but this is less obvious.

For the GR the aim was to minimize gaps and therefore part of the spliced GR comes from inside the 7" liner and is suppressed in the interval 1757-1803.5 m.

The laterolog curves (RLA), NMR (CMR), Caliper (PPC) and the spectral GR curves (Uranium, Thorium and Potassium) have also been spliced and used in the evaluation.

Depth and TVD (TVDSS)

The well and the sidetrack are deviated with a maximum deviation of 38 degrees at 1815 m in the Dinantian. The two surveys were tied together at 1802 m. The result of the deviation is that there is a relatively large difference in measured and true vertical depth (TVD) in this well, at 2000 m measured depth correspond to a TVD of 1796.2 m, more than 200 m shallower.

Log corrections

No environmental corrections or other corrections have been applied.

Evaluation of Dinantian (1596-2303 m MD)

There are no density-neutron logs in this well and therefore the lithology cannot be determined.

In the upper part of the Dinantian, a CMR nuclear magnetic resonance tool was run and it provides a relatively good quality porosity, although there are some high porosity spikes that is not in agreement with sonic and resistivity logs. These high porosities appear in most instances where there are indications of hole rugosity and they are therefore not likely to be correct. A porosity has been calculated from the sonic based on a Limestone matrix with a dtma=160 us/m and a fluid slowness of 620 us/m using the Wylie equation. The sonic porosity calculated result in an acceptable comparison to the total porosity from the NMR (TCMR), see figure 1. A dolomite matrix slowness of 145 us/m was also applied but this was too fast when compared to the total porosity from the CMR (TCMR).

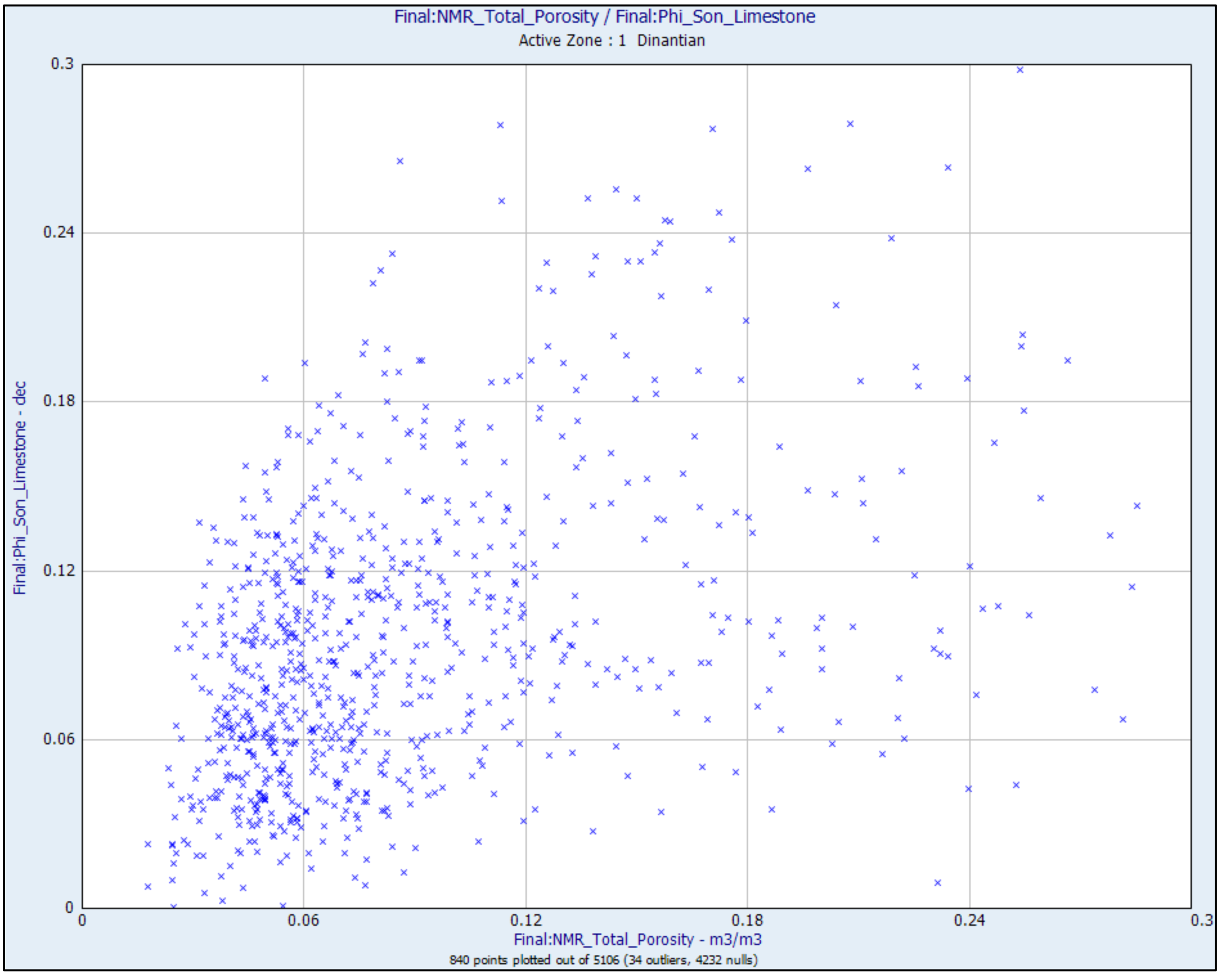


Figure 1. Comparison of Porosity calculated from the sonic applying a Limestone matrix slowness with the total porosity measured by the NMR in the upper part of the Dinantian.

Based on the sonic limestone porosity and the deep laterolog resistivity (RLA5) an Rw of 0.25 ohmm has been determined from the Picket plot, cutting out clay indicator (see below) values above 0.2, see figure 2. The corresponding salinity to an Rw=0.25 ohmm at 68 deg C (estimated mid-point temperature in the Dinantian, see below) is approximately 12 000 ppm. Based on this Rw, corrected for the formation temperature, and the deep laterolog a resistivity porosity is calculated:

Porosity_Resistivity = (Rw/Deep_Resistivity)**0.5

The result is a resistivity porosity that overall matches the sonic porosity and the NMR (CMR) porosity quite well. The final porosity is a combination of the sonic Limestone porosity and the resistivity porosity taking the minimum of the two. For the bottom part of the 8 ½" hole, below 1728.5 m, into the lost circulation zone, the resistivity porosity is used due to no other porosity available.

There is a gap in porosity from 1751.1 to 1804 m caused by the lack of any logs to calculate porosity. Below this depth, the porosity is calculated from the minimum of the sonic and resistivity porosity.

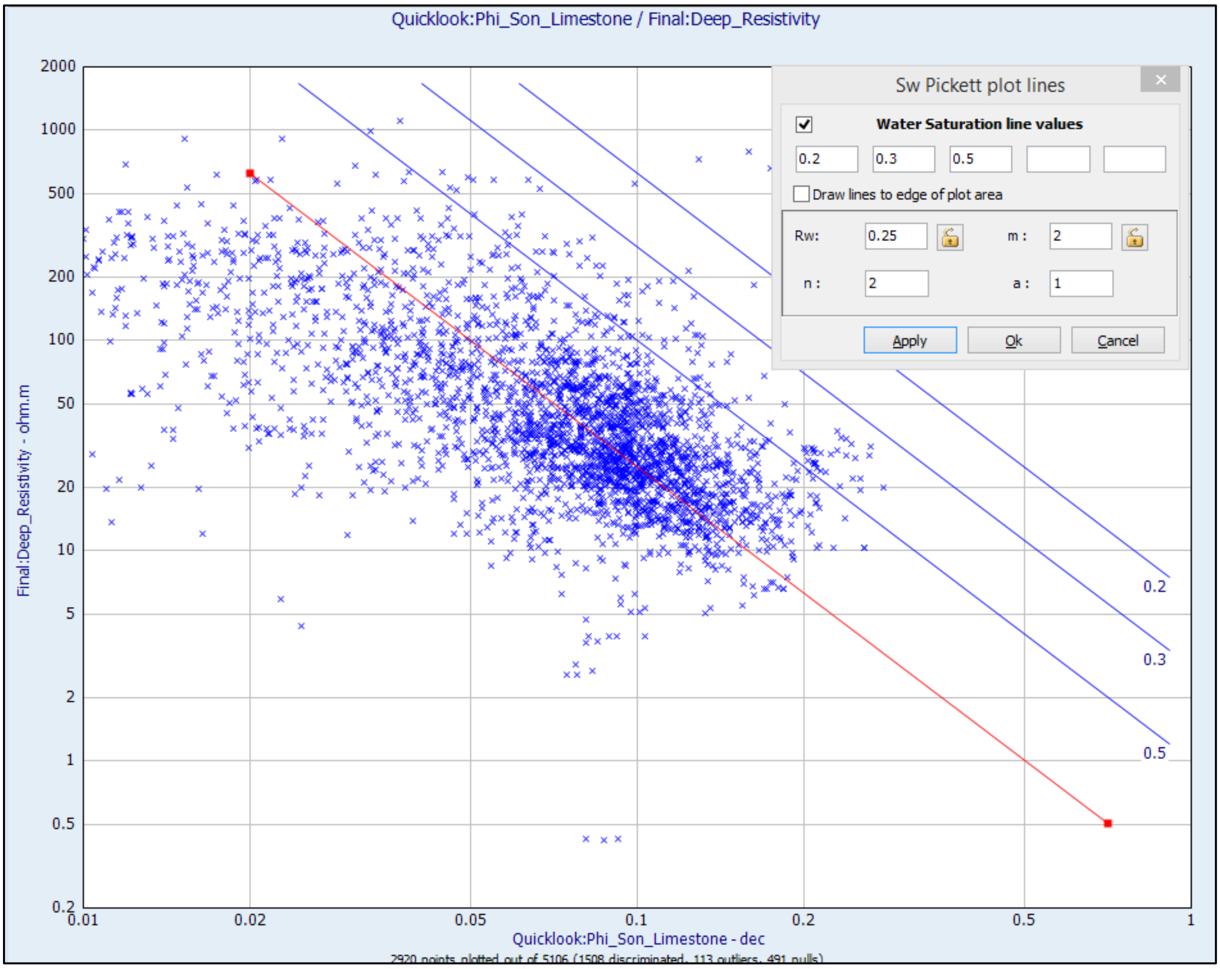


Figure 2. Picket plot of deep laterolog resistivity versus sonic Limestone porosity.

A clay indicator has been derived from the Potassium concentration in the upper part of the Dinantian and from the GR in the remaining section. This is used to cut out porosity intervals with a too high clay content and in this well this is essential, due to the high clay content in the Dinantian. Where only GR exist, below 1729 m, it is likely that some intervals will be cut out due to high GR caused by Uranium that have no or little clay. The clay indicator based on a Potassium concentration of 0.002 for 0 % clay and 0.05 for 100 % clay. The resulting equation is:

Clay_Indicator = -0.04167 + 20.83 * Potassium concentration

The clay curve is based on a clean GR of 18 and a 100 % shale GR value of 250 and the resulting equation is:

Clay Indicator (GR) = -0.07759+0.004310*GR

The final Clay Indicator is the Clay Indicator based on the Potassium concentration down to 1729 m and the Clay Indicator based on the GR below this depth.

The clay indicator cut off applied to the porosity is 0.1.

The lithology displayed in the last track on the evaluation plot, see below, is the cuttings interpretation from the Petrel project. It is quite likely that the proportions of the different minerals are exaggerated for some and suppressed for others and this could for example be the case for Dolomite, which is very likely to be too high.

Result

The result of the evaluation can be seen in the log evaluation plot.

The sums and averages for this well are provided in the table and graph below. The clay indicator cut off is 0.1 and the cavernous part has been left out. The reason for this is that the porosity in this section is very uncertain and also that it skews the distribution and does not relate to the matrix porosity.

Gross	Net	Net/Gross	Average Porosity	Average clay content	Average Porosity * net	Normalized Porosity*Net	Porosity cut off
TVD	TVD	TVD					
m	m	fract	fract	fract	m	fract	fract
578,41	282,84	0,489	0,059	0,053	16,71	1,000	0,00
578,41	263,17	0,455	0,063	0,054	16,64	0,996	0,01
578,41	245,49	0,424	0,067	0,056	16,37	0,980	0,02
578,41	221,76	0,383	0,071	0,058	15,78	0,944	0,03
578,41	198,07	0,342	0,075	0,060	14,95	0,895	0,04
578,41	172,40	0,298	0,080	0,062	13,79	0,825	0,05
578,41	146,60	0,253	0,084	0,065	12,37	0,740	0,06
578,41	107,76	0,186	0,091	0,068	9,85	0,589	0,07
578,41	78,93	0,136	0,097	0,069	7,69	0,460	0,08
578,41	50,99	0,088	0,104	0,071	5,32	0,318	0,09
578,41	25,43	0,044	0,114	0,072	2,90	0,174	0,10
578,41	15,42	0,027	0,120	0,078	1,86	0,111	0,11
578,41	6,94	0,012	0,127	0,080	0,88	0,053	0,12
578,41	1,47	0,003	0,136	0,075	0,20	0,012	0,13
578,41	0,15	0,000	0,147	0,086	0,02	0,001	0,14
578,41	0,00	0,000			0,00	0,000	0,15

Column 7 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, see figure 3 below.

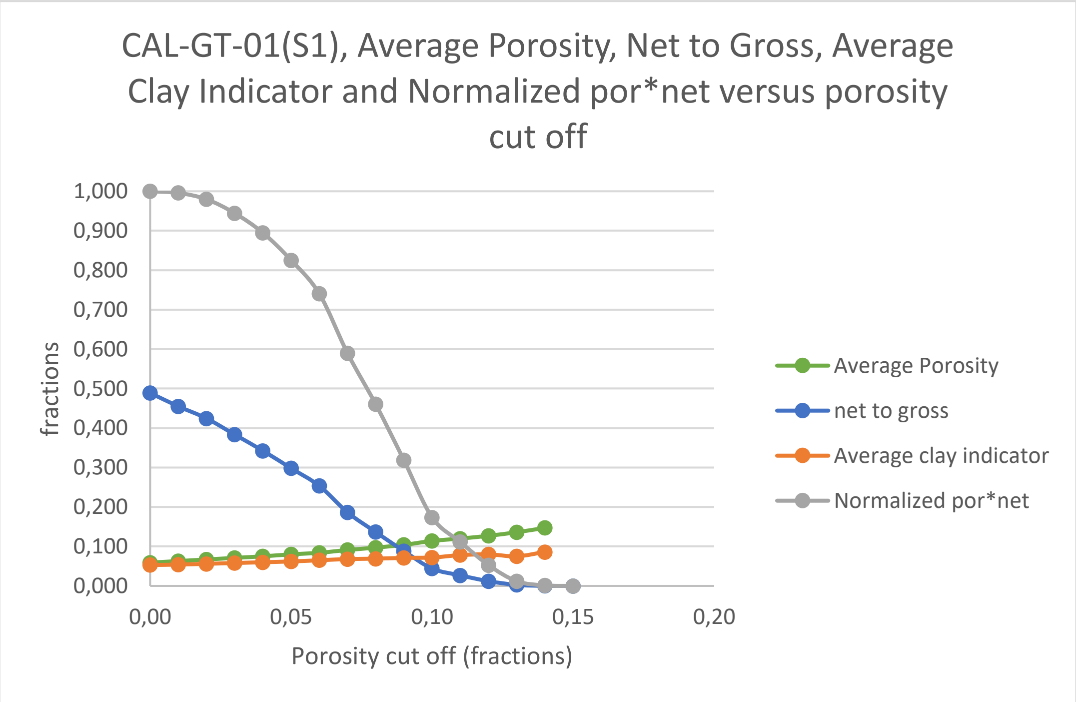


Figure 3. Average Porosity, net to gross, average clay indicator and normalized porosity*net versus porosity cut off.

In this well the net to gross decreases gradually with higher porosity cut offs and the normalized product of porosity and net decreases only marginally for the lower porosity cut offs and reaches a maximum decrease at a porosity cut off of 7 %. The average porosity with no porosity cut off is high at 6.3 % and increases slowly initially and then accelerating with higher porosity cut off. There is no porosity exceeding 15 % in the matrix part of this well. The average of the clay indicator starts at a high value of 5.4 and gradually increases with porosity cut off. The latter is obviously limited to values below 0.1.

Discussion

Due to the lack of a neutron (density) log, it is not possible to evaluate the mix of Limestone and Dolomite.

Below 1729 m there are no spectral GR logs that can separate Uranium from the two clay indicating elements, Potassium and Thorium. The result is an uncertain clay indicator determination, causing possible cut out of valid porosity.

The 8 ½" hole interval below 1728,5 m has cavernous porosity and was drilled with total losses. The porosity in this interval is only calculated down to 1751.1 m, using the resistivity and this determination is very uncertain. It is however certain that the porosity is very high in this interval, mostly calculated to above 30 %. The laterolog resistivities show separation in this interval with the deepest measurement being the highest, indicating that the deeper the reading, the more rock is seen.

No porosity can be determined in the interval 1751.1-1804 m due to the lack of logs.

The porosity in this well is anomalously high compared to the majority of the Dinantian sections penetrated in the Netherlands and only the wells in the Californie project have comparable porosity. The clay content is also higher and there is a very strong relationship between the porosity and the clay indicator, see figure 4. Much of the porosity is therefore caused by the clay content in the Limestone matrix. With the limited set of logs available, it is not possible to make any conclusions on what proportion of the porosity is caused by the clay. The only indicator present is the free fluid indicator from the NMR in the intervals where there is a good relationship between the final porosity and the total NMR porosity. In these sections, the free fluid index is typically below 3 % and only occasionally above this level. The matrix permeability is therefore very likely low, also when the porosity is high, >3-4% and higher. It is believed that most of the matrix porosity in this well has low or even very low permeability.

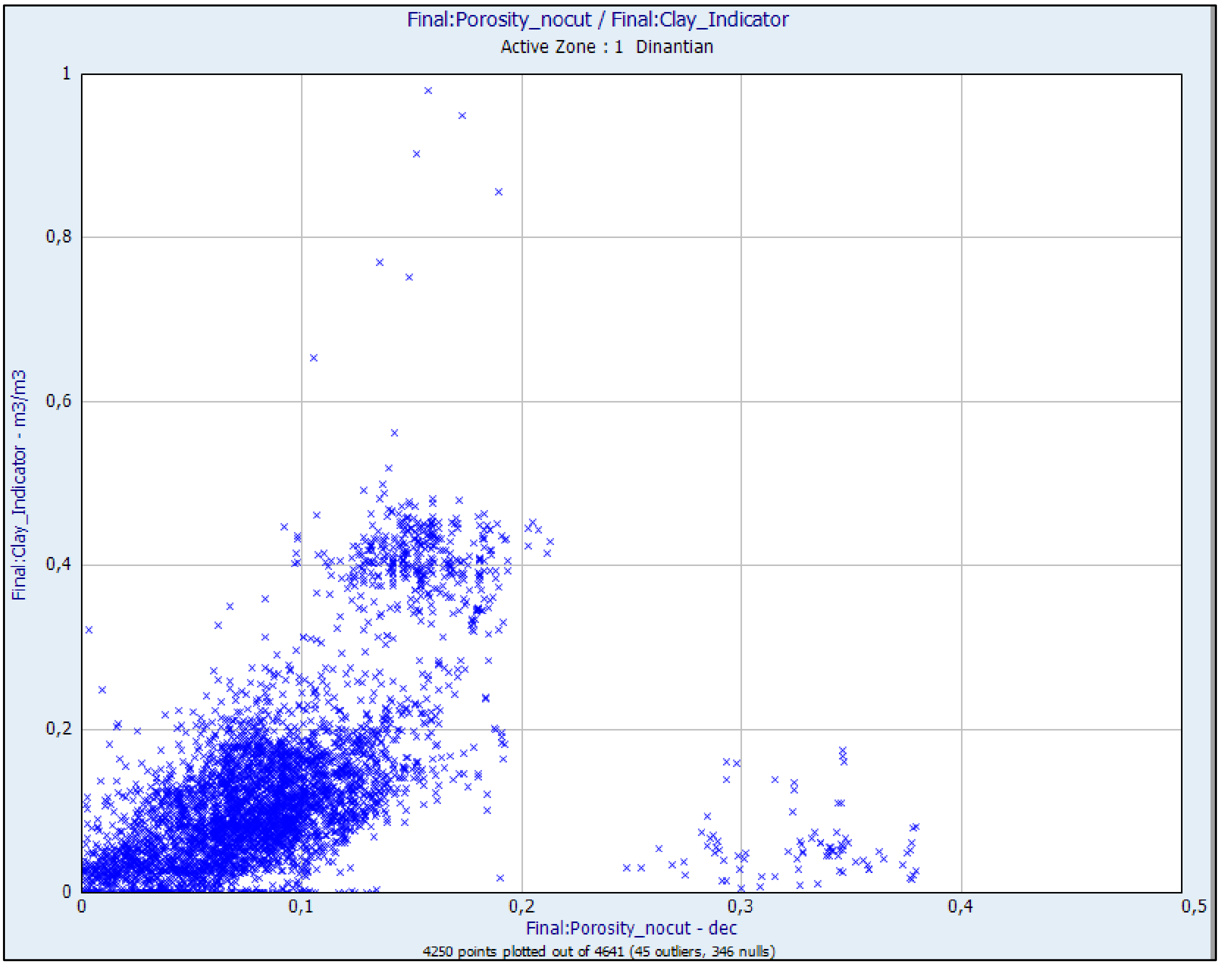


Figure 4. Clay Indicator versus porosity (no cut off applied).

Flow potential

A production test was executed on 6-7th of August 2012. The production test is a multi-rate step test in which the ESP frequency has been increased with 5 Hz approximately every 3 hours. Between each step, the well has been shortly closed-in (too short for build-up analysis). The plot below (Fig 5) shows the resulting pressure (measured at ESP) and corresponding flow rate for each step. The average production index for each step can be calculated. The results are plotted in Fig 6. It becomes clear that the PI decreases for an increasing ESP frequency (larger drawdown), which is contra-intuitive. However, the short time frame of each step could account for this observation, because this could imply that the reservoir has not yet reached steady state flow.

The permeability in this reservoir is most likely fracture driven. The pressure disturbance in the wellbore during a production test (BHP<Preservoir) causes the fracture aperture to decrease (closing fractures), which results in a decreasing flow rate over time. In each step, the drawdown is increased, resulting in a larger drainage area. Even though the drainage area increases, the fracture aperture still shows a decreasing trend, which has a negative effect on the the effective permeability of the reservoir (and thus flow rate).

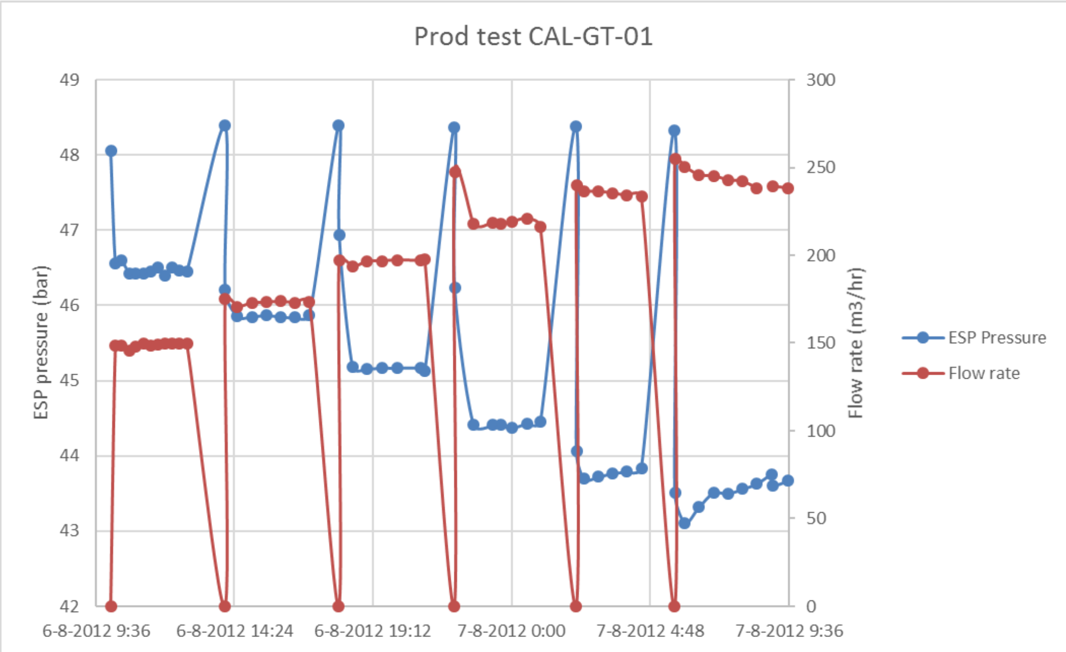


Figure 5. ESP Pressure and Flow rate measurements during the production test (CAL-GT-01)

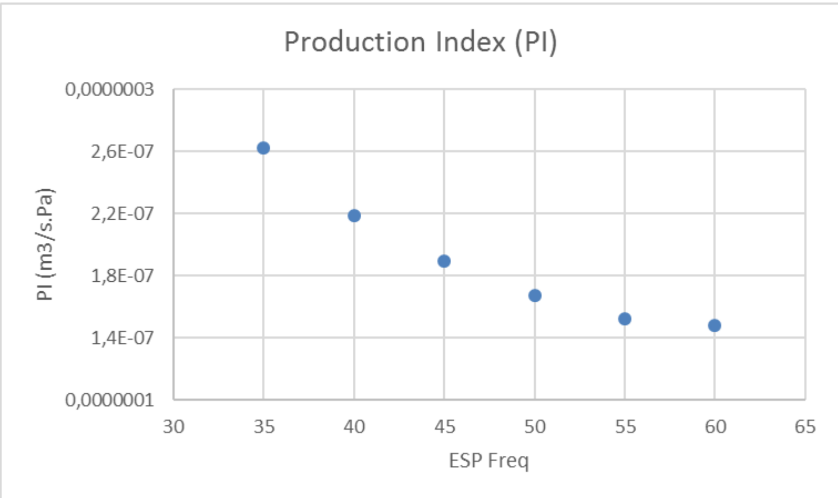


Figure 6. Average production index for each step in the production test (fig 5)

There are no wireline formation tests in this well.

Severe losses including total losses occurred in the 8 ½” hole in the Dinantian and losses continued throughout the 6” hole. The losses appear to be associated with the cavernous interval below 1728.5 m, indicating good permeability in this interval during drilling. The losses and the curing of them probably have caused formation damage that could have changed the flow properties and therefore affected the outcome of later tests.

Formation temperature

Maximum temperatures were recorded on the different logging runs.

In the 12 ¼” hole, a maximum temperature of 65 deg C was recorded at 1360 m (1261.9 m TVD) for both runs.

In the 8 ½” hole, a maximum temperature of 64 deg C was recorded at 1715 m (1554.2 m TVD) on all runs (3).

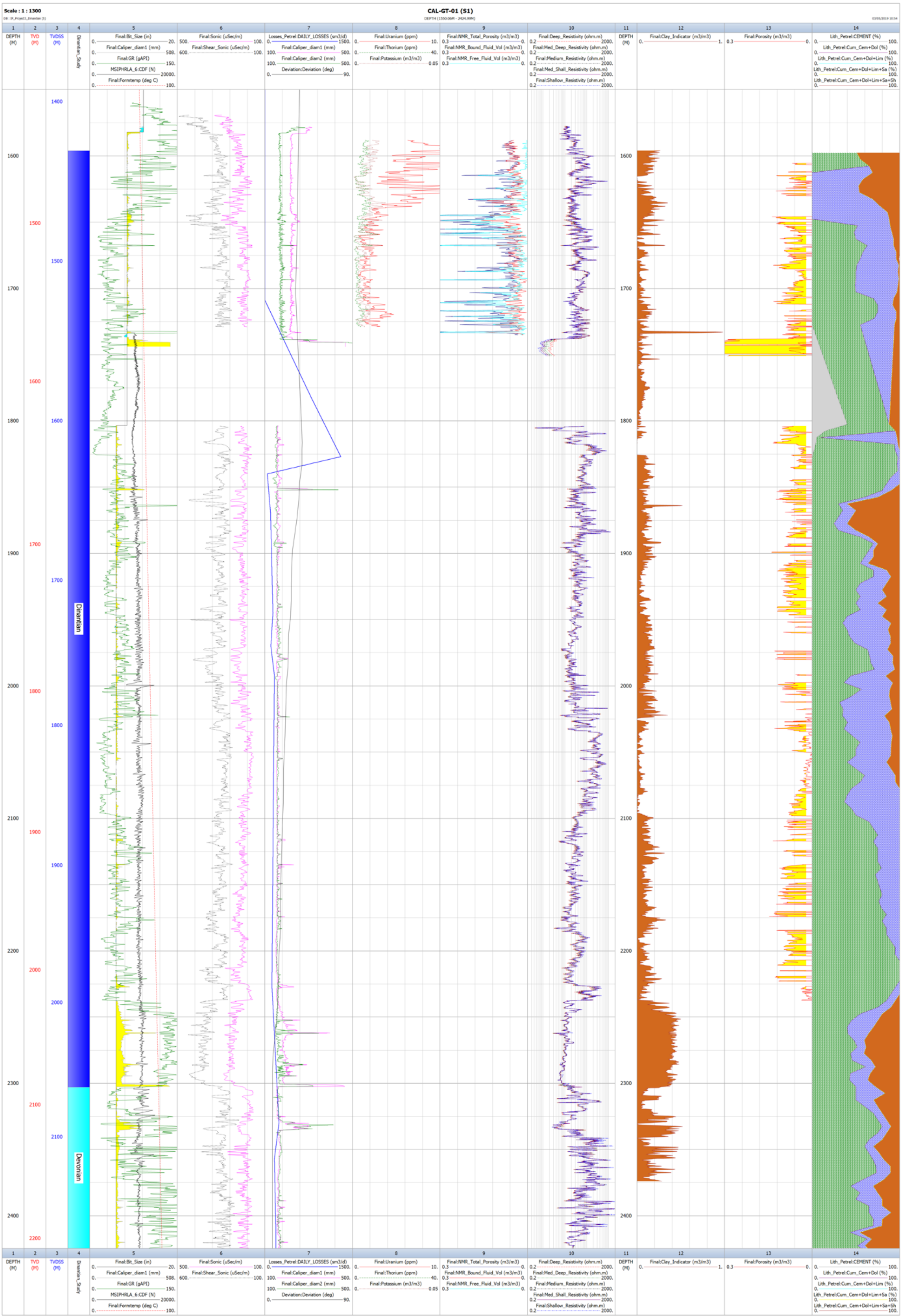
In the 6” hole, a maximum temperature of 89 deg C was recorded at 2690 m (2470.6 m TVD) on the single logging run.

Because only one maximum temperature has been recorded on each logging suite, no Horner extrapolation can be performed. The maximum temperature in the 12 ¼” hole is almost certainly too high and should not be used. The other temperatures are almost certainly slightly below the actual formation temperature. The temperature in the 6” hole is probably the temperature closest to the actual formation temperature due to much lower circulation rates and therefore less cooling in this size hole. It would therefore be expected that the formation temperature is only a few degrees above the measured of 89 deg C. A conservative temperature of 91 deg C has been used for the calculation of the formation temperature. A surface temperature of 10 deg C has been used and the temperature equation is:

Formtemp = 10 + 0.03279*TVD

The intermediate temperature of 64 deg C at 1715 m (1554.2 m TVD) result in a higher gradient of 0.0347 deg C/m. It is therefore probable that the temperature gradient is higher in the overburden above the Dinantian than in the Dinantian but as no extrapolation temperatures can be derived it was decided that only a single temperature gradient should be used.

Evaluation plot



Well logging summary, CAL-GT-01S

OPERATOR:	CALIFORNIE WIJNEN Geothermie BV
WELL:	Californie Wijnen
WELL BORE:	CAL-GT-01
FIELD:	Californie
PLATFORM:	onshore
COUNTRY:	NETHERLANDS

WELL LOGGING SUMMARY

Hole section:	Main Service:	Generic Logs	Service Company:	Mode:	Run #:	Sub file:	Run Type	Pass Direction (Up/Down)	Date:	Interval Top (m):
17 1/2"	GR-AITH-EMM-SGTN-DTCH-LEQHT	GR-Caliper 4 and 6 arm - Induction - SP	SCHLUMBERGER	EWL	1	1	Main	UP	23-May-2012	25
12 1/4"	GR-USIT	GR-Ultra Sonic Imager Tool	SCHLUMBERGER	EWL	1	1	Main	UP	10-JUN-2012	0
12 1/4"	GR-SP-HNGS-HRLA-PPC	GR-SP-Spectral GR-High resolutio laterolog array tool	SCHLUMBERGER	EWL	2	2	Main	Up	10-JUN-2012	805
12 1/4"	GR-CMR	GR-Nuclear Magnetic Resonance Log	SCHLUMBERGER						10-JUN-2012	850
8 1/2"	SP-HRLA-PPC-GR	GR- High resolution laterolog-SP	SCHLUMBERGER						1-JULY-2012	1577
8 1/2"	GR-FMI-MSIP-PPC	GR-Borehole Image-Sonic Scanner Log	SCHLUMBERGER	EWL	3	3	Main	Up	01-JULY-2012	1577
8 1/2"	GR-HNGS-CMR	Gr-Spectral GR-Nuclear Magnetic Resonance Log	SCHLUMBERGER	EWL	1A	2	Main	Up	02-JULY-2012	1587
8 1/2"	MSCT	Mechanical sidewall coring	SCHLUMBERGER						02-JULY-2012	1584,5
6 "	SP-IS-PPC-DSI-HRLA-GR	GR-SP-High resolution Laterolog	SCHLUMBERGER		4		Main	Down	30-JULY-2012	1803,5
6 "	SP-IS-PPC-DSI-HRLA-GR	GR-SP-High resolution Laterolog	SCHLUMBERGER		4		Main	Down	30-JULY-2012	1803,5
	Mudlog	GR	Geoservices							485
	Mudlog	Litholog	Geoservices							26

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