Geothermal Energy Reservoir Characterization; Case Study of Bunter Reservoirs, Zuid Holland, Netherlands.

By

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Abstract
On the basis of the effort by the Delft University of Technology to produce hot water for heating purposes (Delft Geothermal Project, DAP), the Buntsandstein Reservoirs of the Triassic Detfurth and Volpriehausen Formations in the West Netherlands Basin have been identified and delineated for geothermal energy development. The objective was to identify the quality and indicate the distribution of these geothermal energy reservoirs for the purpose of generating electricity. In the light of this, four seismic surveys are interpreted and integrated with well data, which are analysed and interpreted for stratigraphic and structural frameworks, followed by analysis of petrophysical properties. Two porosity/permeability relationships are used for calculating net-to-gross (N/G) at various permeability cut-offs such as 0.1mD, 1mD, 10mD and 100mD. Net sand ranges from 0.14m to 58.04m for 10mD and 0.1mD permeability cut-offs respectively. Based on different scenarios the average porosity ranges from 6.5% to 16.2% and N/G ranges from 0.6% to 30.8%. Heterogeneity remains an issue of concern, but it is believed that they will generally not serve as a barrier or baffle to flow. The zone in and around Wells MON-03, P18-A-02, P15-01 and P15-14 in the central part of the study area show the best reservoir intervals based on average porosity and N/G values. This zone is therefore recommended as the most plausible for the geothermal energy development project, it is also characterized with depths in the excess of 3,000m and estimated temperatures in excess of 140^0C, which are well above the required values for generating electricity.

Keywords: Geothermal energy, reservoir quality, formations, petrophysical, porosity/ permeability

Introduction

In the recent past, there has been renewed efforts by the Delft University of Technology to produce hot water for heating purposes (Delft Geothermal Project, DAP), but the target reservoir (Delft Sandstone) is shallow and the water that will be produced is below 100^0C, making it not suitable for electricity generation[1]. The Triassic formations in the Netherlands is buried deep enough (>3000m) to have formation water temperature in excess of 100^0C[2]. Aquifers that are of potential interest for the heating purposes occur at depths starting from 100 m to more than 3000 m in Permian, Lower Triassic and Lower Cretaceous sandstones and in two Tertiary sand units[3]. This work therefore targets the Triassic formations, where it is believed water with temperature above

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[1]Dufour, F.C. & Heederik, J.P., 2019. Early geothermal exploration in the Netherlands 1980–2000. European Geothermal Congress, 11–14 June 2019, The Hague, the Netherlands. Conference proceedings.
[2]Bonté,D., Van Wees J. D. and Verweij J. M. (2012). Subsurface temperature of the onshore Netherlands: new temperature dataset and modelling. Netherlands Journal of Geosciences/Geologie en Mijnbouw 91(4): 491–515.
[3]Mulder, E. de, Geluk, M.C., Ritsema, I., Westerhoff, W.E., Wong, T.E. (Eds), (2003). De ondergrond van Nederland, Geologie van Nederland, deel 7; Peeters, Herent, België; 379pp.

100^0C will be present for generation of electricity[4]. In an earlier part of the work, the authors have identified and indicated the potential geothermal reservoirs to be located within the regions around the central part of the study area. The objective of this current work is to investigate the spatial variations of the reservoir properties of the Triassic Bunter sandstone in the Zuid Holland area of the Netherlands. To this effect, 3D seismic and well log data of the Triassic formation acquired within the Delft region were analysed and interpreted. Then, parameters such as the reservoir thickness, net/gross, porosity, permeability, were analysed, from which recommendations on the development of geothermal energy based on a smarter approach are made.

Stratigraphy of the study area

This study is situated in the West Netherlands Basin (WNB) bordered by the Zandvoort ridge and the Ijmuiden high to the north, the London-Brabant Massif to the south and it merges with the Roer-Valley Graben towards the south-east[5]. Stratigraphically, two groups of the Triassic formation have been defined: the Lower and Upper Germanic Trias, separated by an Netherlands whereas the Upper Germanic group is preserved in the Mesozoic basins (Table 1). The Triassic lies conformably over the Zechstein group (Permian), while itself is unconformably overlain by unconformity[6] The Lower Germanic group is deposited and preserved over large parts of the younger sequences of the Altena, Nedersaksen, Rijnland and North Sea Groups[7] The sediments of the lower Germanic Triassic Group dates back to the Early Triassic (Scythien) and it consists of The Lower Buntsandstein, the Volpriehausen, the Detfurth and the Hardegsen Formations. The Main Buntsandstein Subgroup consists mainly of sands in the southern part of the Netherlands, with considerably varying thickness, in contrast to the underlying Lower Buntsandstein Formation. This subgroup overlies the Lower Buntsandstein with a minor unconformity and contains the best reservoir intervals, the Volpriehausen Formation and the Detfurth Formation**.**

Table 1: Stratigraphic framework of the Triassic in the Netherlands. The intervals best suited for geothermal exploitation are marked in yellow[8].

	Formation	Lithology	Thickness m	Depth Range m
Upper Germanic Trias	Sleen	Grey Shales and Brown Limestone	45	40-4450
	Keuper	Evaporites and Claystone	>1000	850-3900
	Muschelkalk	Limestone and Evaporites	500	outcrop-3950
	Roet	Evaporites, Clay- and Siltstone	300	outcrop-4200
	Solling	Sand- and Claystone	125	90-4250
Lower Germanic Trias	Hardegsen	Sand- and Claystone	200	680-4350
	Detfurth	Sand- and Claystone	100	270-4500
	Volpriehausen	Sand- and Claystone	200	125-4750
	Lower Buntsandstein	Varicoloured Sand- and Claystone	400	80-5000

[4]Breede, K., Dzebisashvili, K. and Falcone, G. (2015). Overcoming challenges in the classification of deep geothermal potential. Geothermal Energy Science 3: 19 –39.
[5]Van Balen, R.T., Van Bergen F and De Leeuw C (2002). "Modelling the hydrocarbon generation and migration in the West Netherlands Basin, the Netherlands". In: Netherlands Journal of Geosciences, 79: 29-44.
[6]Marinus E. D. Remco M. G. and Douglas T. G. (2015). Reservoir Geology and Geothermal Potential of the Delft Sandstone Member in the West Netherlands Basin". World Geothermal Congress, Melbourne, Australia, 19-25 April.
[7]De Jager, J.(2007). "Geological development", In: Wong, Th. E., Batjes, D.A.J. & De Jager, J., Geology of the Netherlands, Royal Netherlands Academy of Arts and Sciences, p. 5-26.
[8]Geluk, M.C. (2007). *"Triassic"*. In: Wong, Th. E., Batjes, D.A.J. & De Jager, J., Geology of the Netherlands, Royal Netherlands Academy of Arts and Sciences, p. 85-106.

The Volpriehausen Formation displays its greatest thickness, over 200 m, in the Dutch Central Graben and the Broad Fourteens Basin[9]. It reaches 100 m in the Ems Low and 150 m in the Roer Valley Graben. The Volpriehausen Unconformity at the base of the formation locally cuts up to several tens of meters into the Lower Buntsandstein Formation. It consists of arkosic sandstones with quartz content slightly below 50%. It is cemented by high percentages of calcite and dolomite, especially in its lower part. The occurrence of the Detfurth Formation is restricted to the Early Triassic lows as a result of uplift and erosion prior to deposition of the Solling Formation. The depositional thickness of the formation displays considerable variation: 60–100 m in the Dutch Central Graben, 50–80 m in the Ems Low and 20–40 m in the West Netherlands Basin, Roer Valley Graben and Broad Fourteens Basin. In the West Netherlands Basin and Roer Valley Graben the formation consists entirely of sandstones. For geothermal energy, three main prospective reservoir intervals are identified[10] inclusive of the Permian Rotliegendes sandstones, the Lower Triassic sandstones and the Lower Cretaceous sandstones with the Lower Triassic sandstones being the target reservoir for this study. In the lower Triassic (Lower Germanic Triassic), the Detfurth and Volpriehausen intervals are best suited for geothermal exploitation (Table 1).

Methods Used

Four 3D seismic surveys namely L3NAM1985P, L3NAM1991A, Z3NAM1990D and Z3AMC1989A, each with area cover of 146.6 km^2, 414.5 km^2, 767.2 km^2 and 544.6 km^2 correspondingly, were interpreted. Using industry-standard interpretation and modelling package and following Lee and Collett[11] and Schlumberger[12] methods, the interpreted seismic data are integrated with well data, which are analysed and interpreted for stratigraphic and structural frameworks, followed by analysis of petrophysical properties. Thirty (30) wells intersected the Triassic (Detfurth and Volpriehausen) Formations, out of which only nine (9) wells had core data sufficient for correlation and petrophysical interpretation purposes. The wells are evenly spread over the study area and therefore serve as a good representation of the conditions in the entire area. The focus for the petrophysical interpretation is on the Top Detfurth to the Base Volpriehausen (Table 2).

A 3D grid of the area was generated using a suite gridding programme, from which isopach/ thickness and depth maps of the target levels, Detfurth and Volpriehausen were generated along

[9]Van Adrichem Boogaert, H. A. & Kouwe, W.F.P., 1993: "Stratigraphic nomenclature of the Netherlands, revision and update by RGD and NOGEPA". In: Mededelingen Rijks Geologische Dienst (RGD), nr 50.
[10]Lokhorst, A & Wong, Th. E., (2007). "Geothermal Energy". In: Wong, Th. E., Batjes, D.A.J. & De Jager, J., Geology of the Netherlands, Royal Netherlands Academy of Arts and Sciences, p. 341-346.
[11]Lee M. W. and Collett, T.S. (2008). Integrated analysis of well logs and seismic data to estimate gas hydrate concentrations at Keathley Canyon, Gulf of Mexico, Journal of Marine and Petroleum Geology, Vol. 25, Issue 9: 924-931.
[12]Schlumberger Log Interpretation charts (2016). A publication of Schlumberger, 225 Schlumberger Drive, Sugar Land, Texas 77478, 2016 edition: 16-34.

with the temperature maps. The model layer definition consists of five levels (0 – 4), with the Detfurth and Volpriehausen formations further divided into members (Figure 1). While Volpriehausen formation was divided into the Lower and Upper Volpriehausen Sandstone (Reservoir) and the Volpriehausen Clay Siltstone (Non Reservoir), the Detfurth formation was divided into the Lower and Upper Detfurth Sandstone (Reservoir) and the Detfurth Claystone (Non reservoir). Then, petrophysical parameters were modelled using empirical relations.

Table 2: Gross reservoir thickness for each well.

Well	Top Detfurth (m)	Base Volpriehausen (m)	Gross Thickness (m)
MON-03	2966	3097	131
P18-A-02	4165	4309	144
P15-01	2725	2884	159
P15-14	3186	3349	163
KDZ-02-S1	3285	3408	123
Q16-02	3530	3649	119
WAS-23-S2	2662	2788	126
VAL-01	2826	2921	95
Q13-07-S2	3157	3300	143

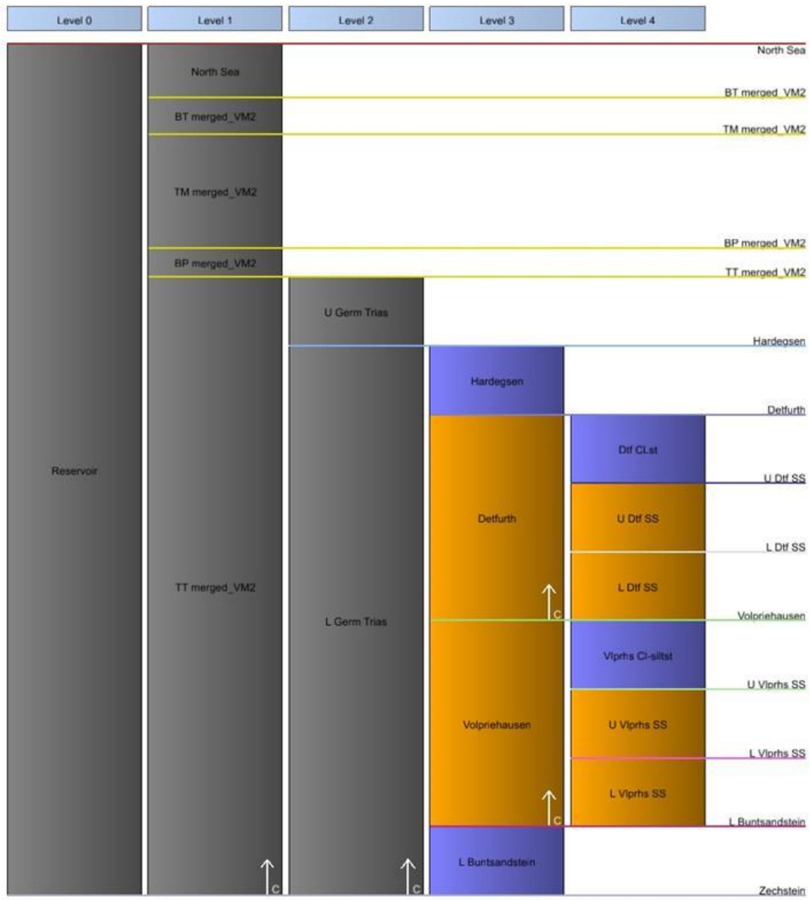

Figure 1: Model Layer Definition for the Detfurth and Volpriehausen formations divided into members.

Using equations (1) and (2), the Volume of clay and the Porosity were calculated from the gamma ray and density log respectively, while the permeability was calculated based on exponential relation (equation 3) generated for permeability and porosity (Figure 2).

$$V_{cl} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}} \qquad (1)$$

$$\phi_{Rho} = \frac{\rho_{\log} - \rho_{\log}}{\rho_{ma} - \rho_{mf}} - V_{cl} * \left(\frac{\rho_{ma} - \rho_{cl}}{\rho_{ma} - \rho_{mf}} \right) \qquad (2)$$

$$K = 0.0025e^{59.279\phi} \qquad (3)$$

Where Vcl is the volume of clay; GRlog is the average gamma ray; GRmax is the maximum value of gamma radiation; GRmin is the minimum gamma ray; ρ_{ma} is the matrix density; ρ_{log} is the average density reading of the formation, ρ_{mf} is the density of the formation in the mud filtrate, ρ_{cl} is density of the clay material. Equation (3) was also used to generate values of 0.1mD, 1mD and 10mD permeability cut-offs, which are used to characterize the net-to-gross (N/G) ratios.

Results and Discussion

The model result based on equation 3 shows, a poor relationship between porosity and permeability, thereby warranting re-calculation of new values for porosity and permeability based on equation 4 (Figure 3).

$$K = 0.00025e^{102.78x} \quad (4)$$

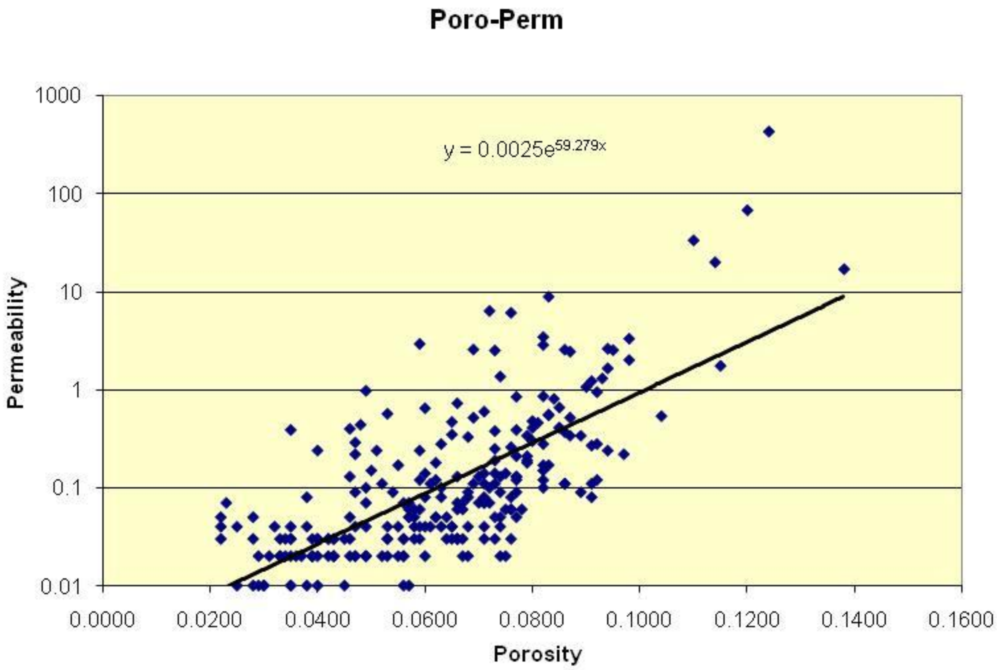

Figure 2: Porosity and permeability relations in well of interest. In the inserted equation, y represents permeability, while x represents porosity.

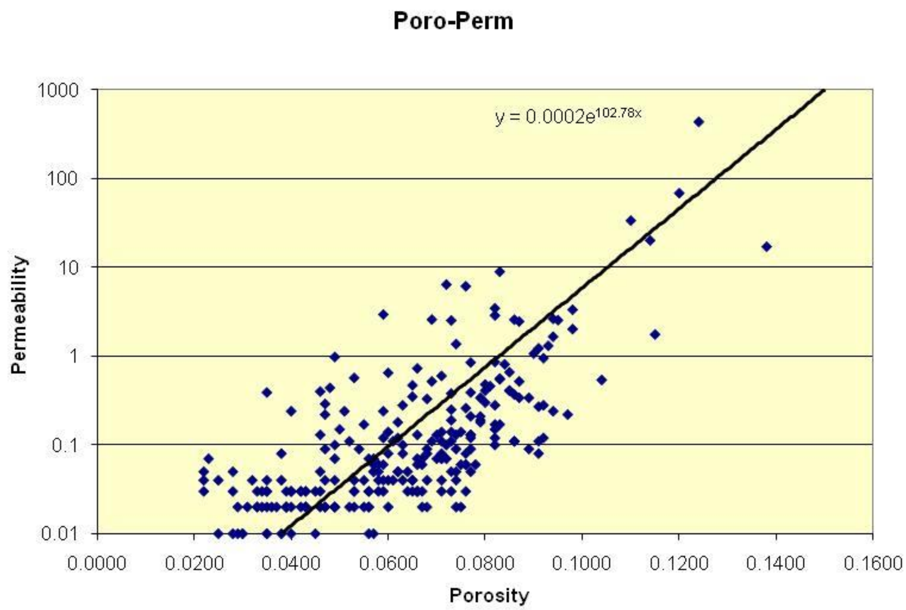

Figure 3: Graph of Porosity and Permeability relationship in wells of interest showing better good values and higher confidence level.

In order to evaluate the reservoirs in terms of the volume of clay, porosity and permeability values, wells were correlated (Figures 4-8), using the Solling Formation as the datum. The general observed trend is that the reservoir thickens from onshore to the offshore region. Corroborating the value in Figure 2, the porosity values are not good enough, but the porous points seem to have excellent permeabilities, which is very crucial for water production.

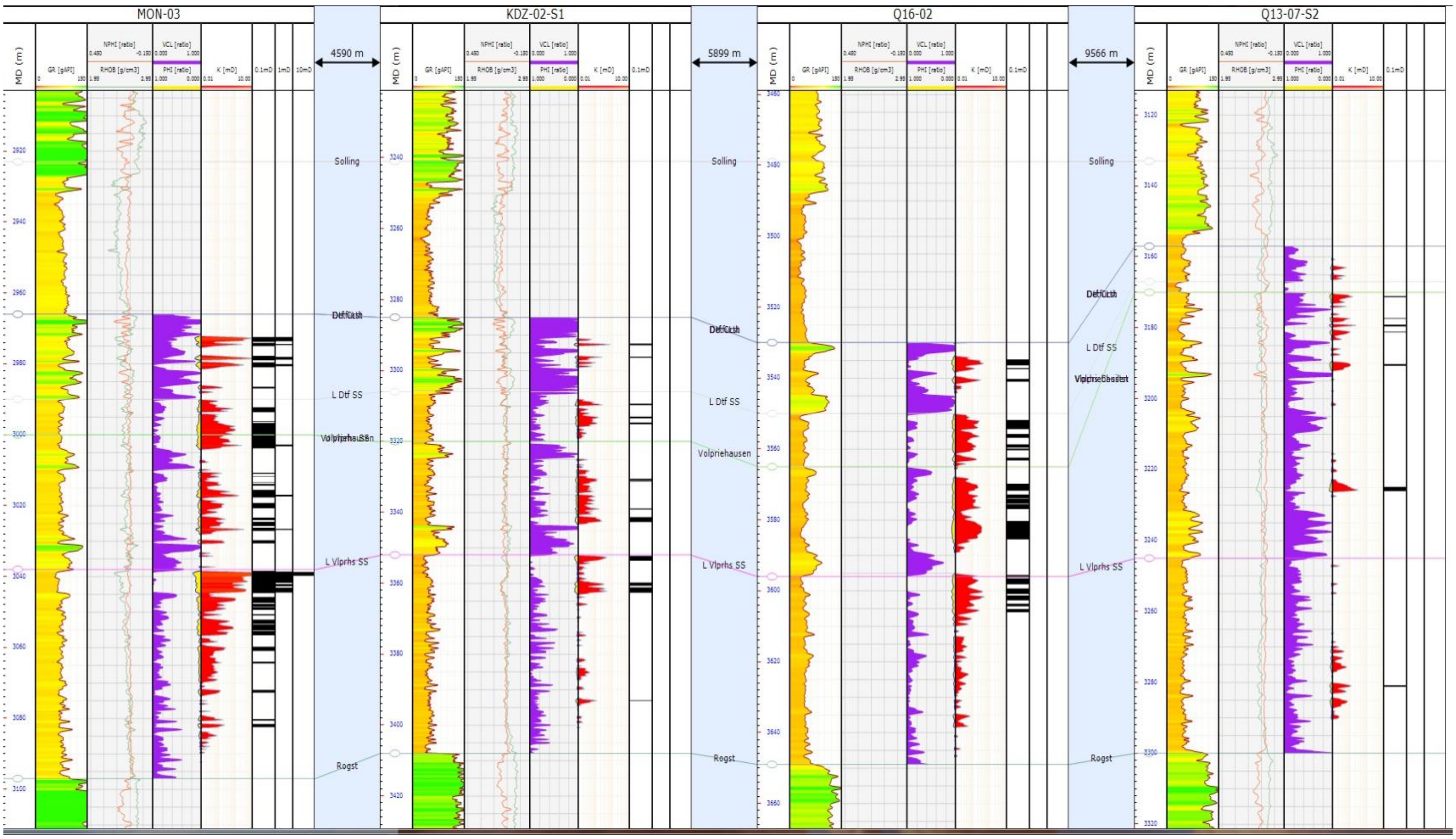

Figure 4: Correlation of top Detfurth to the base Volpriehausen encountered by wells MON-03, Q16-02, KDZ-02-S1 and Q13-07-S2. Top of the shaly Rogenstein Formation is chosen as the base of the Volpriehausen. The Triassic is believed to have been deposited in a quiet environment; hence, the thickness does not vary significantly through the correlated areas. Here, wells MON-03 and Q16-02 have higher porosities and good permeable levels observed compared to KDZ-02-S1 and Q13-07-S2. Therefore, in the region especially around Q13-07-S2, it is believed that the reservoir quality will not be very good. This is also visible from the Vcl which is relatively high throughout the objective interval.

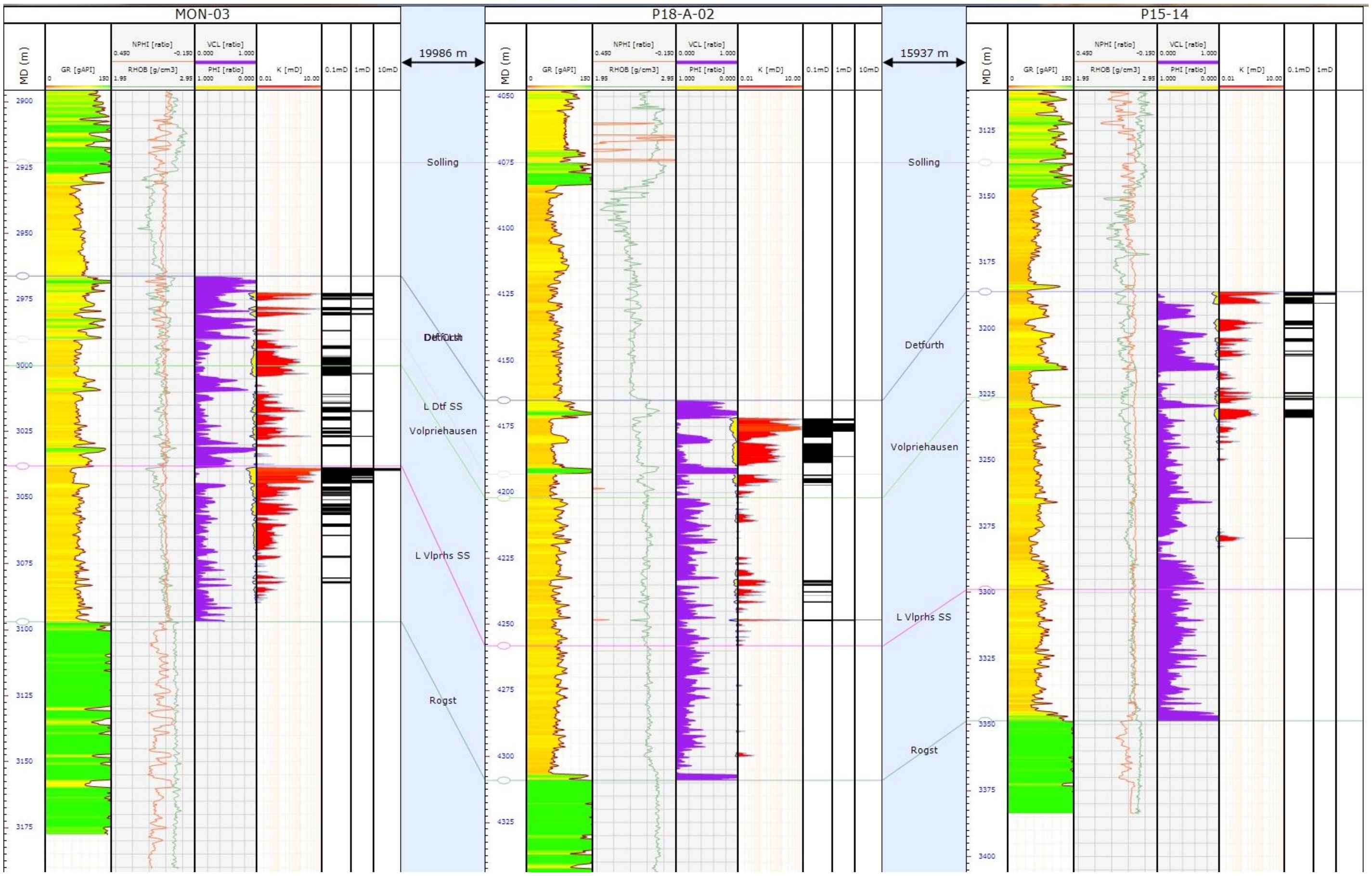

Figure 5: Correlation of top Detfurth to the base Volpriehausen encountered by wells MON-03, P18-A-02 and P15-14. The observed trend all through the correlated area is that, the upper portion of the reservoir shows good porosity and permeability values; Hence, the Detfurth Formation is believed to have better connectivity and higher water production values and of better reservoir quality than the Volpriehausen. The region within and around Wells MON-03, P18-A-02 and P15-14, SE of the mapped area, also appear to have better quality when compared to the other regions.

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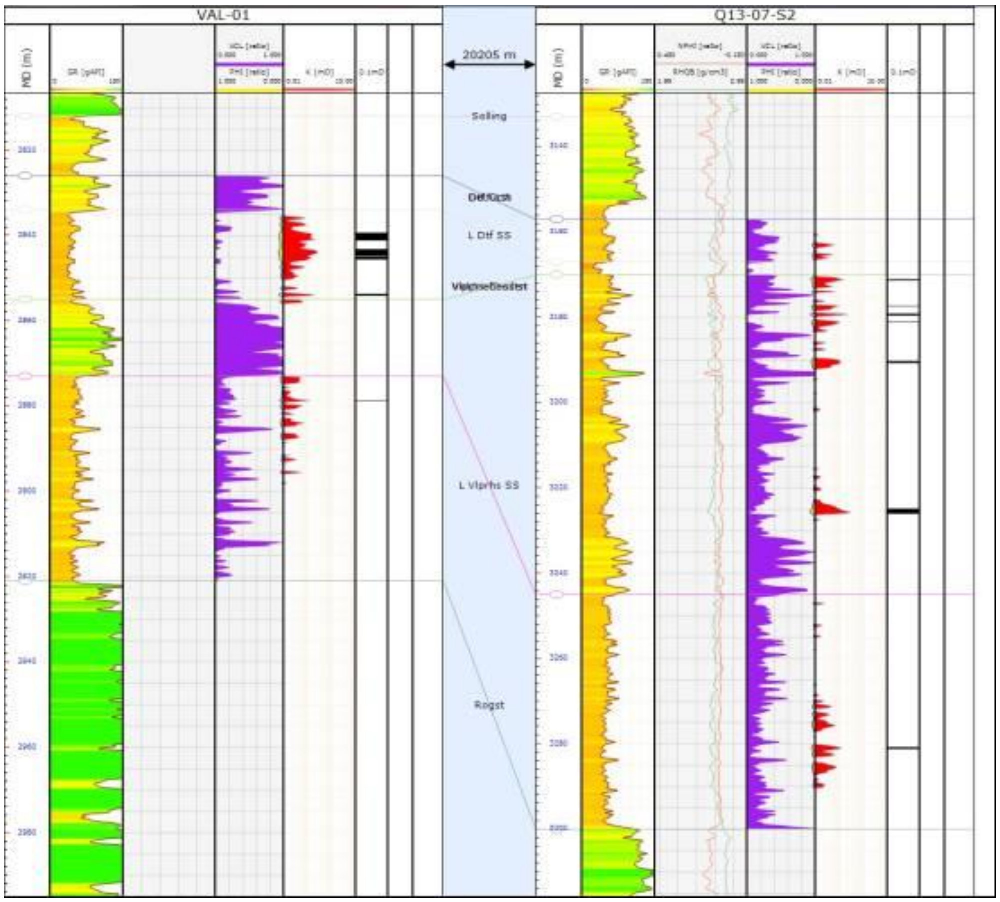


Figure 6: Correlation of top Detfurth to the base Volpriehausen encountered by wells Val-01 and Q13-7-52.

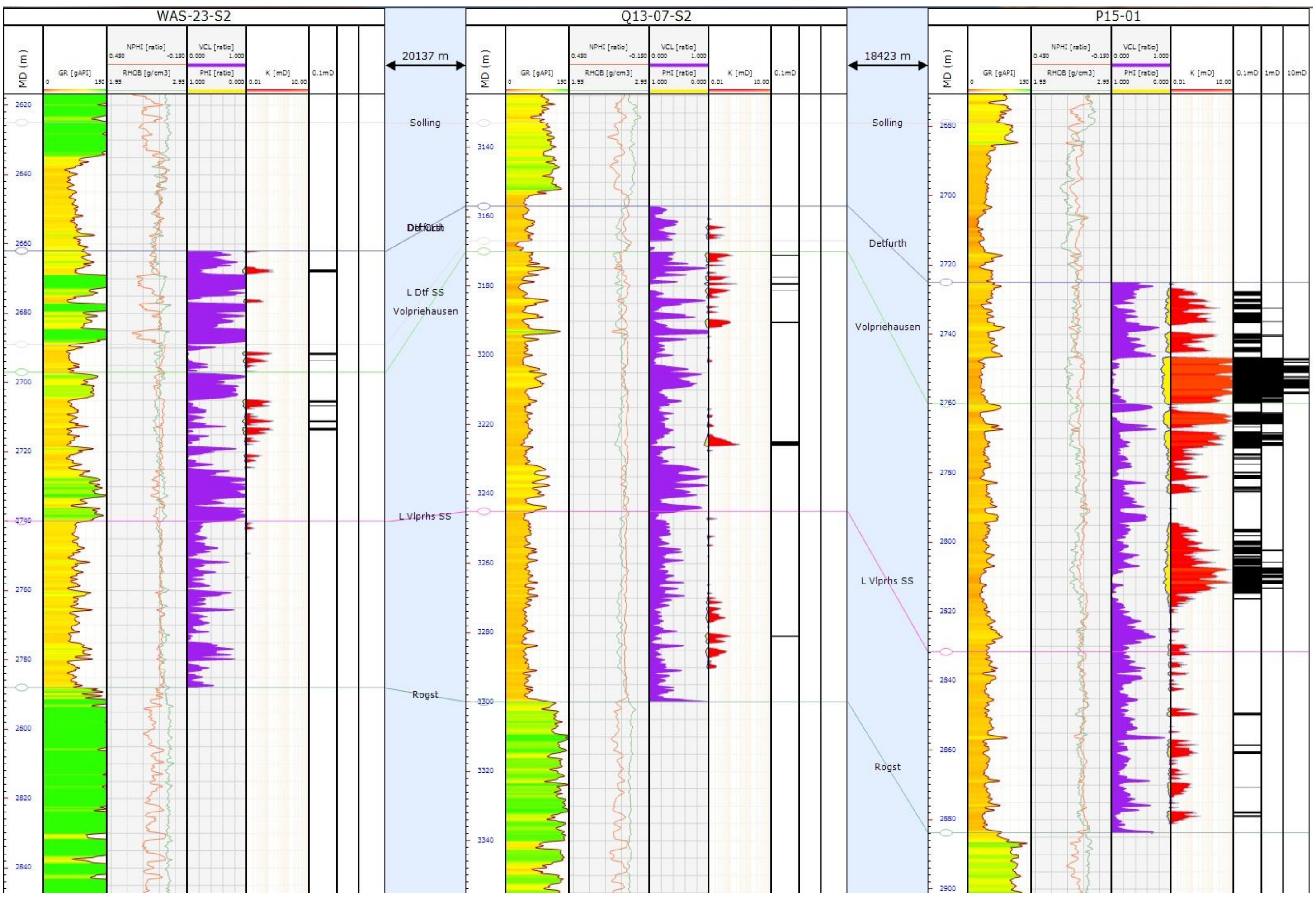


Figure 7: Correlation of top Detfurth to the base Volpriehausen encountered by wells WAS-23-52 Q13-7-52 and P15-01. The reservoir in Well P15-01 is exceptionally of good quality, especially in the upper part of the reservoir interval.

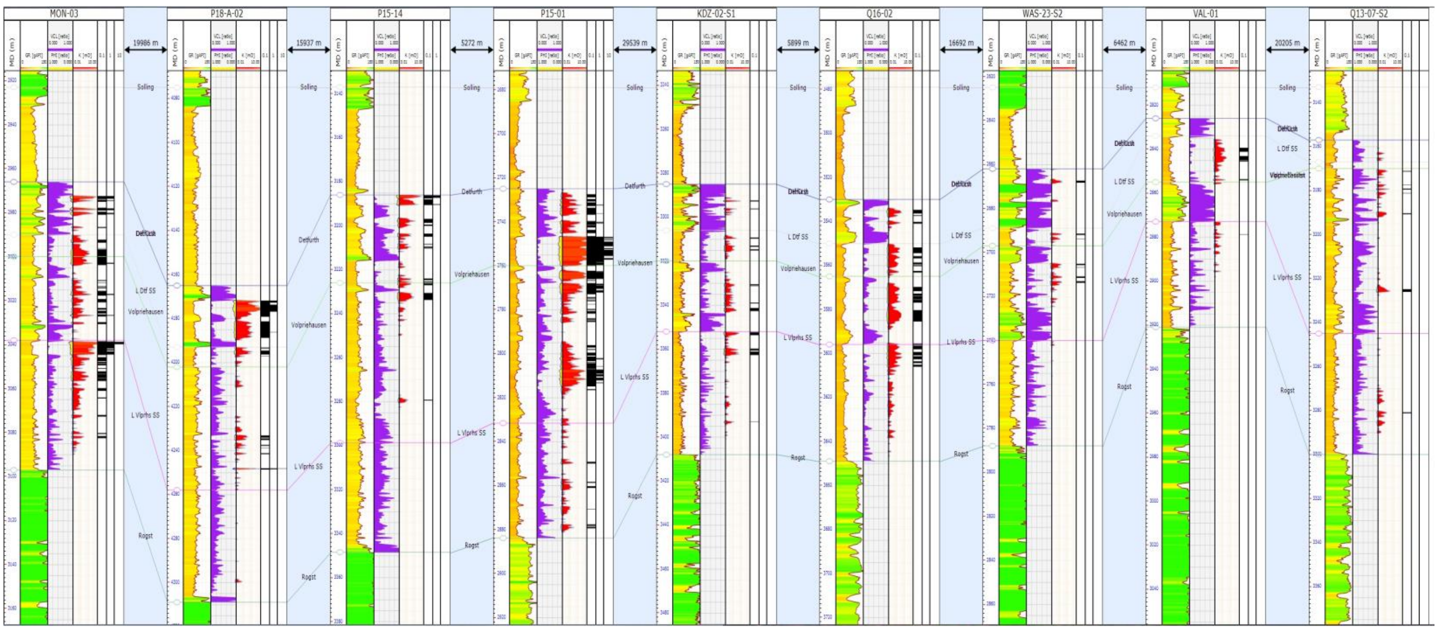


Figure 8: Correlation of top Detfurth to the base Volpriehausen encountered by all the wells with core data, showing a regional correlation of the mapped area. In general, it is observed that the reservoir thickens toward the offshore domain and thins towards the coastal domain. The individual levels indicate no sudden change thickness but appear more like sheet in terms of geometry. Generally, it is believed that the Triassic deposits are sheet-like/sheet-sands.

Reservoir Parameter modelling

Both the gross and net thicknesses of the reservoir interval in each of the wells were calculated (Table 3). The net thickness was calculated based on 0.1mD, 1mD and 10mD cut-off values of the N/G, showing optimistic to pessimistic case. Generally, the interval contains enough thick sequences to be able to contain large quantities of water needed for daily production. On the basis of second scenario for arriving at N/G with good values of parameters (Figure 3), the gross and net thicknesses were calculated (Table 4). However, the 0.1mD cut-off values remained the same for the two scenarios. The 1 and 10mD cut-offs showed an increase in N/G for each Well. There is also a permeability increase in Scenario 2 which is good for connectivity and more water production (Figure 9).

Table 3: Gross and net thicknesses of the reservoir intervals in the wells in the first scenario

				0.1mD cut-off	1mD cut-off	10mD cut-off
Well	Top Detfurth (m)	Base Volpriehausen (m)	Gross Thickness (m)	Net Thickness (m)	Net thickness (m)	Net thickness (m)
MON-03	2966	3097	131	40.35	9.30	1.05
P18-A-02	4165	4309	144	20.74	4.75	0.14
P15-01	2725	2884	159	58.04	25.28	0.16
P15-14	3186	3349	163	14.67	1.30	
KDZ-02-S1	3285	3408	123	8.36		
Q16-02	3530	3649	119	26.42		
WAS-23-S2	2662	2788	126	3.78		
VAL-01	2826	2921	95	4.75		
Q13-07-S2	3157	3300	143	3.15		

Table 4: Gross and net thicknesses of the reservoir intervals in the wells based on the second scenario.

				1mD cut-off	10mD cut-off	100mD cut-off
Well	Top Detfurth (m)	Base Volpriehausen (m)	Gross Thickness (m)	Net Thickness (m)	Net thickness (m)	Net thickness (m)
MON-03	2966	3097	131	19.91	7.34	1.97
P18-A-02	4165	4309	144	13.10	4.03	1.87
P15-01	2725	2884	159	38.16	18.92	10.02
P15-14	3186	3349	163	5.22	0.98	
KDZ-02-S1	3285	3408	123	1.23		
Q16-02	3530	3649	119	1.67		
WAS-23-S2	2662	2788	126			
VAL-01	2826	2921	95			
Q13-07-S2	3157	3300	143			

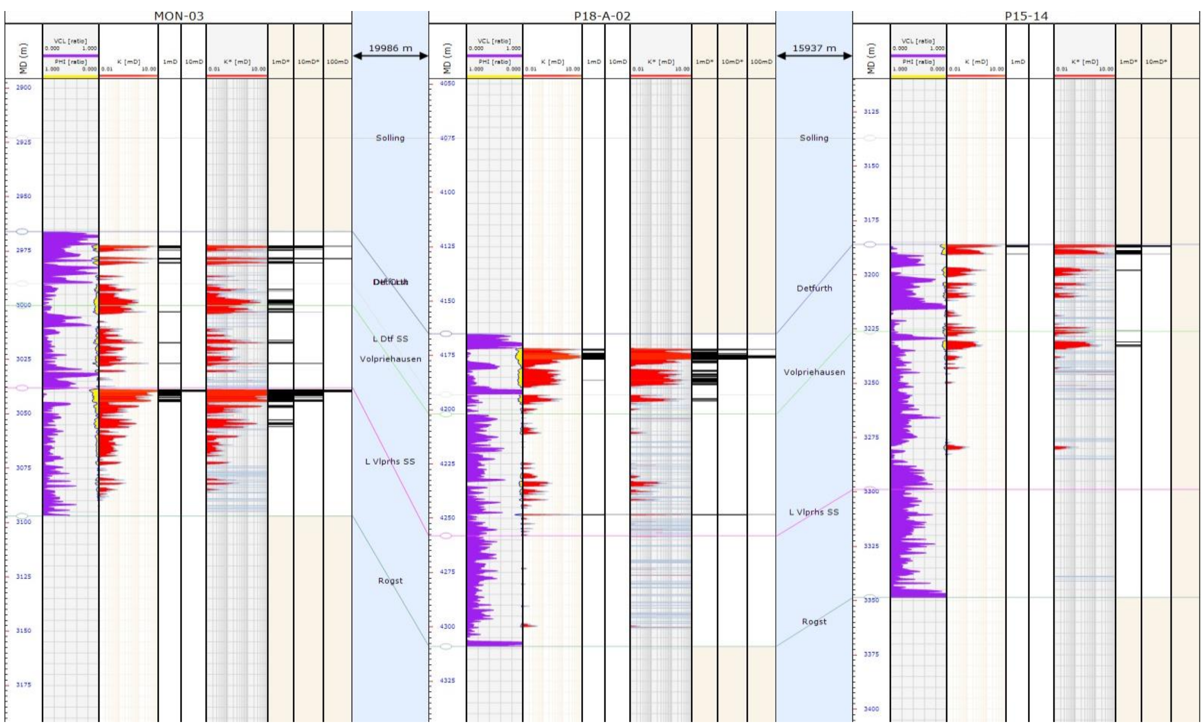


Figure 9: Correlation wells for comparison between the base case and the second scenario, which is of good

values of reservoir parameters. The second scenario includes K*, 1mD*, 10mD* and 100mD*. Comparing this with K, 1mD and 10mD of the base case immediately shows that there is an increase in N/G and K values. This therefore shows that given more weight to the higher porosity and permeability values leads to a more optimistic view.

For the Net/Gross, the Wells MON-03, P18-A-02, P15-01, and P15-14 show the best reservoir intervals based on the calculated average Porosity and N/G values (Table 5). Therefore, the zone in and around these wells in the mapped area is believed will have the best reservoir quality. (Table 6) shows the results for the second scenario showing good values of reservoir parameters (higher porosity and permeability values).

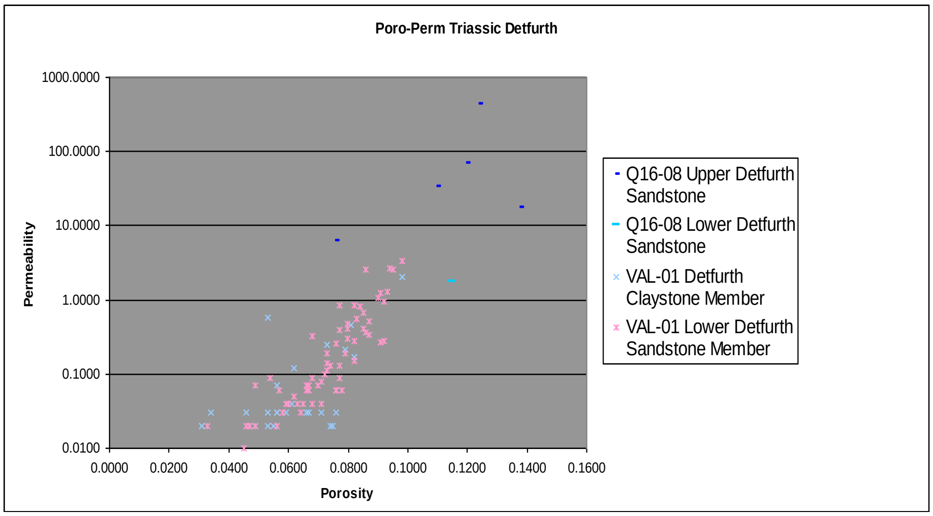
Table 5: N/G, Average Porosity and Average Volume of Clay calculated in the reservoir intervals in the Wells.

Well	0.1mD cutt-off			1mD cut-off			10mD cut-off		
	Av VCl	Av Por	N/G	Av VCl	Av Por	N/G	Av VCl	Av Por	N/G
MON-03	10.80%	8.60%	30.80%	9.70%	12.20%	7.10%	0%	16.20%	0.80%
P18-A-02	7.80%	9.00%	14.40%	2.60%	12.40%	3.30%	0.80%	15.10%	0.10%
P15-01	15.40%	9.80%	36.50%	8.60%	12.60%	15.90%	2.90%	15.00%	0.10%
P15-14	9.50%	7.90%	9.00%	2.10%	11.40%	0.80%			
KDZ-02-S1	7.50%	7.10%	6.80%						
Q16-02	5.50%	6.90%	22.20%						
WAS-23-S2	6.80%	6.60%	3.00%						
VAL-01	0.50%	6.70%	5.00%						
Q13-07-S2	9.50%	6.50%	2.20%						

Table 6: N/G, Average Porosity, and Average Volume of Clay calculated in the reservoir intervals in the Wells based on the second scenario which gives more weight to the good values. NB 0.1mD cut-off is not repeated because they are the same values for the two scenarios.

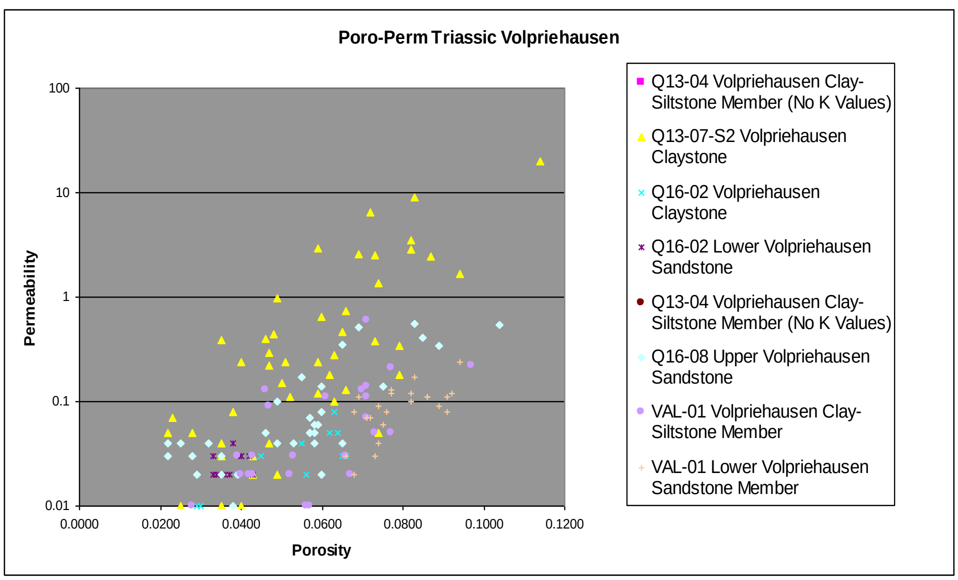
Well	1mD cutt-off			10mD cut-off			100mD cut-off		
	Av VCl	Av Por	N/G	Av VCl	Av Por	N/G	Av VCl	Av Por	N/G
MON-03	10.80%	10.50%	15.20%	10.20%	12.60%	5.60%	10.70%	14.90%	1.50%
P18-A-02	6.60%	10.20%	9.10%	2.30%	12.80%	2.80%	1.20%	13.70%	1.30%
P15-01	11.90%	11.40%	24.00%	7.10%	13.30%	11.90%	3.50%	14.50%	6.30%
P15-14	3.80%	9.50%	3.20%	1.50%	11.90%	0.60%			
KDZ-02-S1	4.70%	8.50%	1.00%						
Q16-02	2.80%	8.20%	1.40%						
WAS-23-S2									
VAL-01									
Q13-07-S2									

Evaluation of primary porosity and permeability indicates both porosity and permeability are generally low in the mapped area. But, it is expected that permeability and connectivity are enhanced locally through fracturing, since the target horizon is highly faulted; the fault system will serve as conduit for water, and hence a higher level of connectivity and more water production. Heterogeneity remains an issue of concern due to the high level of Vcl in some of the intervals. But it is believed that they will generally not serve as barrier or baffle to flow. The Porosity-Permeability trend maps of the Detfurth and Volpriehausen are shown in Figures 10 and 11. Wells MON-03, P18-A-02, P15-01, and P15-14 show the best reservoir intervals based on the average porosity and N/G values. Well Q16-08 has the best values for both the Detfurth and the Volpriehausen Formations. This corroborates the results of earlier interpretations from subsurface maps and estimated temperatures, showing that a large part of the area around well Q16-08 in the central blocks looks promising with depths grated than 3,000m which and temperature greater that 1400C, which are required qualities needed to produce electricity. The reservoir quality here is good as well based on the fact that most of the area within the area also falls within the part of the WNB where it is believed that the Detfurth and Volpriehausen Formations have Aeolian facies that occupy more than 50% of the rock unit. Generally, porosity is higher at the upper part of the reservoir interval, implying that the Detfurth Formation will generally have a better reservoir quality than the Volpriehausen Formation.



Well	MD (m)
Q16-08	3877-3913
VAL-01	2826-2855

Figure 10: Porosity-Permeability relationship for the Detfurth Formation in wells Q16-08 and VAL-01



Well	MD (m)
Q13-04	2785-2800
Q13-07-S2	3170-3188
Q16-02	3570-3635
Q16-08	3930-3947
VAL-01	2855-2881

Figure 11: Por-Perm Volpriehausen for Wells Q13-04, Q13-07-S2, Q16-02, Q16-08 and VAL-01.

Discussions

A few drawbacks can be foreseen in the Dutch situation, based on the result of this study; the aquifers, suitable for geothermal exploitation are the same as the oil and gas-bearing reservoirs, implying considerable overlap. A deep-seated geothermal project positioned close to a producing oil or gas field or a gas or CO2 storage facility, therefore may cause subsurface interference. The extraction of geothermal energy may affect the pressure distribution in or around the oil or gas field or the storage facility. A simulation study[13] concerning the effects of overpressure and temperature changes in the Lower Cretaceous Ijsselmonde Sandstone Member, however, shows that, if water is re-injected into the formation under overpressure conditions, the pressure changes in the vicinity of the wells due to the extraction of geothermal energy are limited (not more than 1 bar at a distance of 1 km). The simulation also shows that thermo-elastic effects may occur as well, depending on the temperature of the injected water. These may amount to 50 bar if the formation is cooled by more than 500C, which would locally cause a compaction of 2 to 3 cm at reservoir level(ca. 1100 m); the effects at surface would be negligible. Such investigations are important in the Netherlands, where public concern about soil subsidence and seismicity due to gas production plays an important role in discussions on the use of the underground.

Another important risk is that the prospective lows have very little well penetration and are usually considerably deeper than the much shallower oil fields. It is however suspected that structuration and formation of highs and lows is relatively late, and that diagenesis predates structuration. This would imply that the shallow oil fields have porosities representative of much greater depths. This is borne out by the fact that there is hardly any relationship of porosity against depth (Figure 12). Evaluation of primary porosity and permeability indicates both porosity and permeability are generally low in the mapped area. But, it is expected that permeability and connectivity are enhanced locally through fracturing, since the target horizon is highly faulted; the fault system will serve as conduit for water, and hence a higher level of connectivity and more water production. Heterogeneity is also an issue of concern due to the high level of volume of clay in some of the intervals. But it is believed that they will generally not serve as barrier or baffle to flow.

[13]Brouwer, G. K., Lokhorst, A. & Orlic, B. (2005). Geothermal heat and abandoned gas reservoirs in the Netherlands. Proceedings World Geothermal Congress 2005, Antalya, Turkey (24–29 April). International Geothermal Association, CD-ROM, art. 1177.

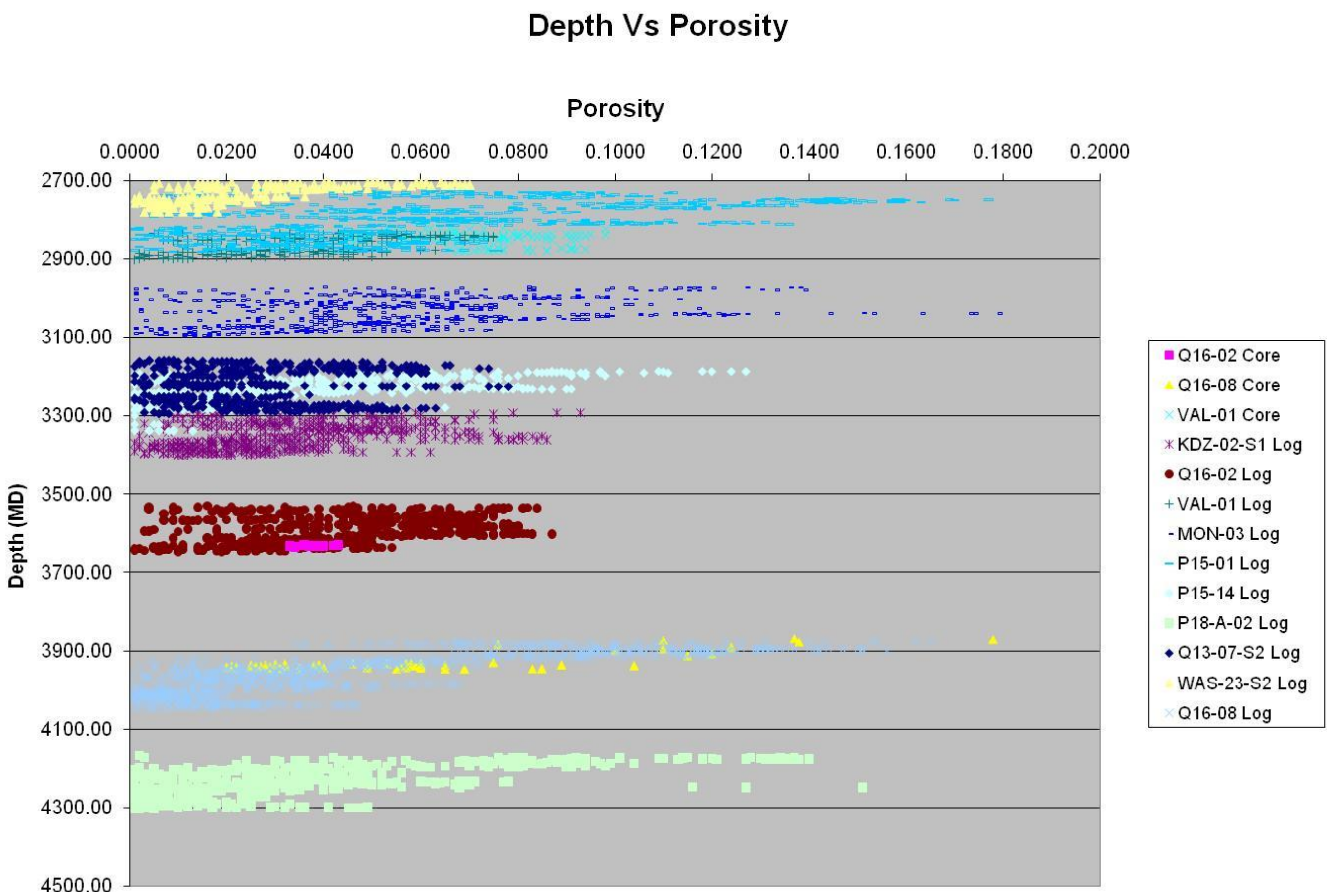


Figure 12: Depth Vs Porosity for Wells that intersected the Triassic. The porosities are both core and log derived as illustrated in the legend. They all fit properly apart from VAL-01 log derived porosity which has some lower values as a result of a high Vcl at the beginning of the reservoir interval in this particular well. Only Wells Q16-02, Q16-08 and VAL-01 have core porosities, all other porosities were derived from logs.

Conclusions

From review of the regional geology and the results of the investigation in this work, the Triassic Detfurth and Volpriehausen Formations encountered in the Delft region of the southern Netherlands are established to be potential good reservoirs for geothermal development. Using empirical relations, petrophysical parameters were modelled and the net reservoir thicknesses were calculated based on the 0.1mD, 1mD and 10mD cut-off values of the N/G, showing an optimistic to pessimistic case. Generally, the level contains enough thick sequences to be able to contain large quantities of water needed for daily production. Wells MON-03, P18-A-02, P15-01, and P15-14 show the best reservoir intervals based on the average porosity and N/G values. Well Q16-08 has the best values for both the Detfurth and the Volpriehausen Formations. Therefore, the zone in and around these wells in the mapped area is believed will have the best reservoir quality. This corroborates the results of earlier interpretations from subsurface maps and estimated temperatures by the authors, showing that a large part of the area around well Q16-08 in the central blocks looks promising with depths greater than 3,000m which and temperature greater that 140^0C, which are required qualities needed to produce electricity. Primary porosity and permeability are generally low in the mapped area, but it is expected that permeability and connectivity are enhanced locally through fracturing. The target formation, the Dethfurth, is highly faulted, and hence the fault system will serve as conduit for water and hence a higher level of connectivity and more water production. Heterogeneity remains an issue of concern due to the high level of Volume of clay in some of the intervals. But it is believed that they will generally not serve as barrier or baffle to flow.

However, it is observed that the aquifers, suitable for geothermal exploitation in the Netherlands, are the same as the oil and gas-bearing reservoirs, implying considerable overlap. A deep-seated geothermal project positioned close to a producing oil or gas field or CO2 storage facility, may cause subsurface interference. Therefore, this factor should be given a special consideration when planning for the geothermal energy development project.

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