Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Permian Rotliegend Reservoir Architecture of the Dutch Koekoekspolder Geothermal Doublet

Johannes G. Veldkamp[1], Harmen Mijnlieff[1], Menno Bloemsma[2], Rick Donselaar[2], Saturnina Henares[3], Allan Redjosentono[4], Gert-Jan Weltje[2]

[1]TNO Energy, P.O. Box 80015, 3508 TA UTRECHT, the Netherlands

[2]Delft University of Technology, Delft, the Netherlands

[3]Universidad de Granada, Granada, Spain

[4]Staatsolie Maatschappij, Suriname

hans.veldkamp@tno.nl

Keywords: reservoir architecture, permeability, gypsum, seismic attribute analysis, geothermal doublet performance, permian

ABSTRACT

The Dutch Koekoekspolder geothermal doublet was drilled in 2011. It targets the Permian Rotliegend reservoir. The reservoir properties encountered were less favorable than expected pre-drill. Post-drill integrated evaluation of vintage data and the new data from the geothermal wells resulted in a refined depositional model of the area. The Rotliegend sediments comprise predominantly horizontally, bimodally laminated fine to coarse grained red sandstones. These sediments were deposited on an aeolian sandflat. Gypscretes were formed on this sandflat in the relative low-lying areas, which coincide with palaeo-lows of the pre-Permian palaeotopgraphy. These gypscretes were periodically exhumed and (partly) eroded providing gypsum grains. These were subsequently incorporated in the predominant quartz rich sand sediments on the sandflat forming typical bimodally laminated Aeolian deposits. The gypscretes are now present as pervasively anhydrite cemented horizons haphazardly vertically distributed. The improved understanding of the formation and occurrence of the gypscretes, in combination with advanced seismic attribute analysis can help in the identification of low-permeability zones that may impede the performance of future doublets.

1. INTRODUCTION

Exploration and production of geothermal energy in the Netherlands started in 2004. It targets the same reservoir formations as the oil and gas companies. One of the targets is the Permian Rotliegend Sandstone from which the majority of the Dutch natural gas is produced (Grötsch and Gaupp, 2011; Grötsch et al., 2012; Ministry of Economic Affairs, 2013). Some 1000 onshore wells penetrate the Rotliegend and additionally 40% of the Dutch onshore has 3D seismic data coverage. Hence, the Rotliegend is a very well-studied stratigraphic interval. Economically viable geothermal energy systems require flow rates of at least 100 m^3/h at temperatures of around 70 - 80 °C. For this the high-permeable aeolian facies of the Rotliegend reservoir interval is explored. Despite the excellent data density and existing detailed geological reservoir models of the Rotliegend, newly-drilled geothermal production wells may have lower than predicted flow rates. This urges the need to refine and detail the existing depositional models. The two wells of Koekoekspolder geothermal doublet are an excellent example for detailing the geological model. The wells, drilled in 2011, target the Rotliegend sandstones at a depth of approximately 1800 meters. Two key parameters in the calculation of the flow rates are the net thickness of the reservoir, and the permeability. The vintage well Kampen-1 (KAM-01-S1) was drilled in 1969. It is located about 1.5 kilometers north of the doublet. It was used as a reference for the pre-drill subsurface model on which the geothermal flow rate prediction was based. Initially, the low flow rates were assumed to be caused by skin issues. However, after remediation of the wells the flow rates invariably remained lower than expected. As a next step, the permeability heterogeneity in the reservoir interval was investigated. In this paper we present results of this reservoir geology study based on the two new geothermal wells, and on re-evaluation of the vintage reference well. The result of this evaluation is tentatively linked to a seismic attribute analysis of the 3D seismic data which is believed to be helpful in determining locations for additional doublets.

2. DATA AND ANALYSIS

The data from the KAM-01-S1 reference well and the two geothermal wells KKP-GT-01 and KKP-GT-02 (Figure 1), a 3D seismic survey and 2D seismic lines were used to construct a 3D subsurface model of the Rotliegend target interval. The wells were tied to the seismic. Top and base of the Rotliegend reservoir were picked on the seismic data. The resulting time-surfaces were converted to depth surfaces using the regional VELMOD velocity model for the Netherlands, optimised for local conditions. Well logs were used to calculate porosity and permeability using standard petrophysical analysis techniques. The core from the KAM-01-S1 well was re-evaluated. A full core description was executed with additional supporting petrographical analysis.

2.1 Reservoir section

The high matrix density in the core plugs in well KAM-01-S1 is caused by abundant disperse anhydrite cement. The Rotliegend succession is subdivided in three zones on the basis of porosity and permeability values (Figure 2): (1) upper zone with relatively low porosity and permeability; (2) middle zone with high porosity and permeability; (3) lower zone with very poor poro-perm values. The poor reservoir quality of the lower zone is at least partly related to the proximity to the base Permian unconformity with related diagenetic deterioration, such as cementation. The net reservoir thickness, porosity and permeability of the two geothermal wells are lower than expected on basis of the KAM-1-S1 well (Table 1). In both wells tight zones are present at different vertical positions with respect to the top reservoir (Figure 2). The tight zones are characterised by high density and low porosity values, suggesting pervasive anhydrite cemented horizons. The wells were drilled using a PDC-bit. Consequently the quality of the cutting samples is very poor. Nevertheless, abundant anhydrite/gypsum is recorded in these intervals. Correlation of the tight zones between the two wells is difficult if not impossible. This suggests that the lateral extent of these zones is less than the well spacing of approximately 1600 meters.

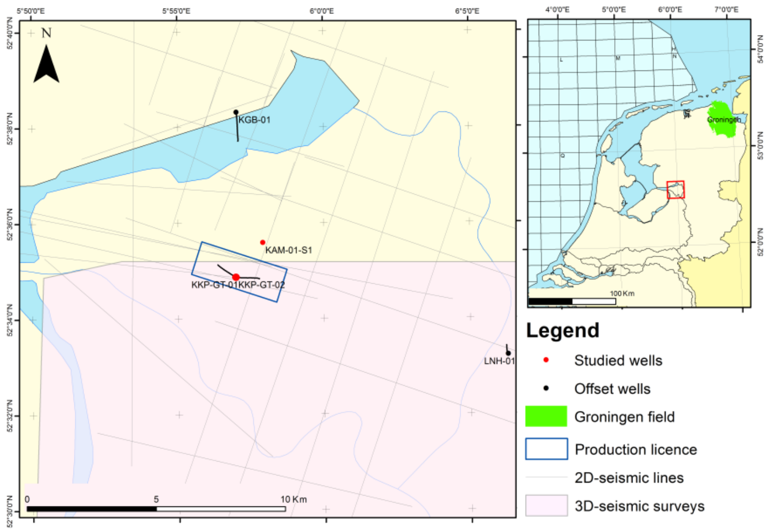

Figure 1 Location of the study area.

Table 1 Reservoir parameters of the key wells.

Reservoir property	KAM-1-S1	KKP-GT-01	KKP-GT-02
Gross Thickness (m)	123.0	93.1	74.0
Net to Gross (%)	94.0	55.0	67.0
Net Thickness (m)	115.0	51.1	49.8
Average porosity (%)	18.3	15.6	19.6
Average permeability (mD)	261.0	59.3	288.8

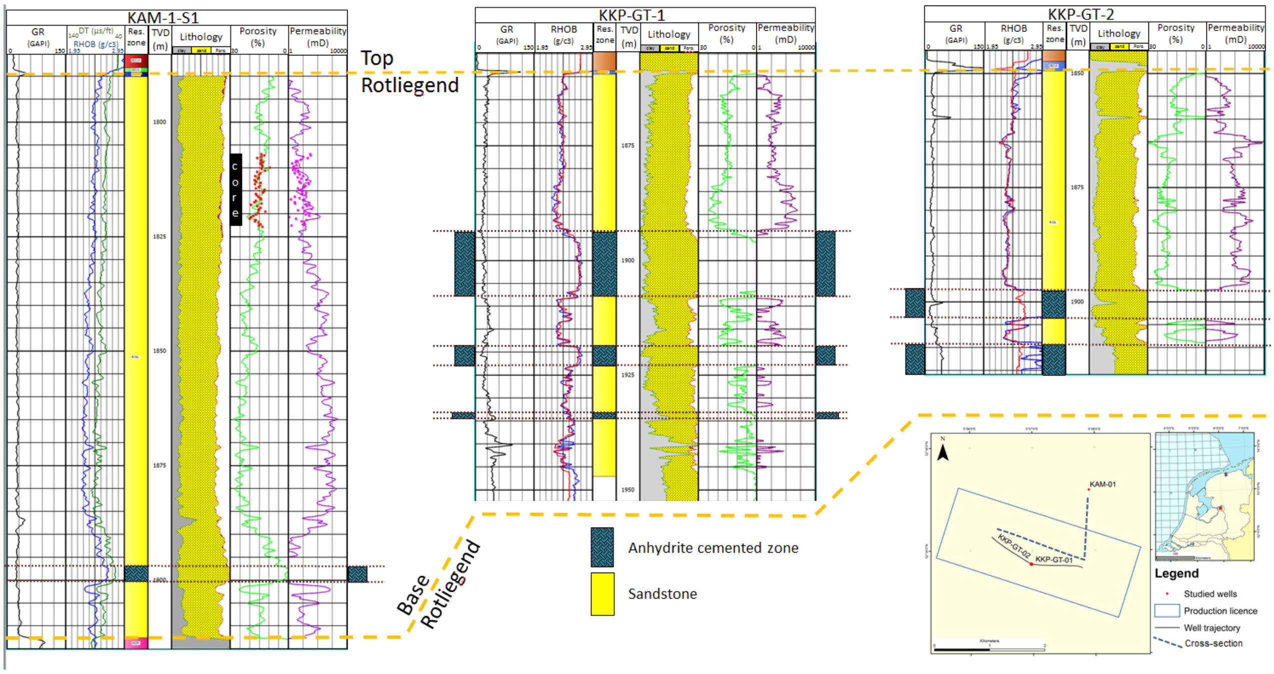

Figure 2 Well correlation panel of the three key wells. The section is flattened on top Rotliegend. Note that in the KKP-GT-1 and KKP-GT-2 wells the base of the reservoir is not reached. The intervals with high density values and low porosity are rich in anhydrite.

2.2 Core description and interpretation

The KAM-1-S1 core was obtained from the upper zone of the Rotliegend succession (Figure 2). It is approximately 16 meters long and consists solely of predominantly horizontally laminated red sandstone (Figure 3). The laminae are arranged in pairs with a bimodal grain size distribution. The boundary between the two laminae is diffuse. The thickness of each pair is 3-6 mm; the lower lamina has a sharp flat base and consists of fine- and coarse quartz grains, white anhydrite grains and white anhydrite cement. The upper lamina consists of red-brown fine-grained quartz sandstone with scarce, dispersed white anhydrite grains. Minor small scale (up to 1 cm thick) cross-beds are present. Few small scouring features are observed. The maximum scour depth is 1.3 cm. The depositional environment is interpreted as a dry aeolian sandflat, outside the dune field area (Henares et al., in prep). This is a more specific interpretation of the general interpretation of the 'windward side sandsea' domain from the Upper Slochteren map of Fryberger et al. (2011).

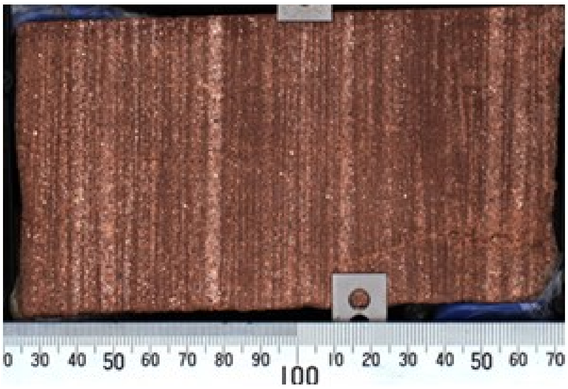

Figure 3 Typical red laminated sandstone of the KAM-1-S1 core. Scale in millimeter.

2.3 Petrographic analysis

Petrographic analysis of the laminated sandstones proved that a significant part of the coarse detrital grains were gypsum grains (Figure 4). The detrital origin of the anhydrite is evidenced by the occurrence of hematite coating on these grains and grain ghosts defined by spherical hematite lines in blocky anhydrite cement (Henares et al., in prep.). The coarse laminae are preferentially cemented with anhydrite cement which also replaces the gypsum grains. The fine grained laminae are preferentially cemented with dolomite cement.

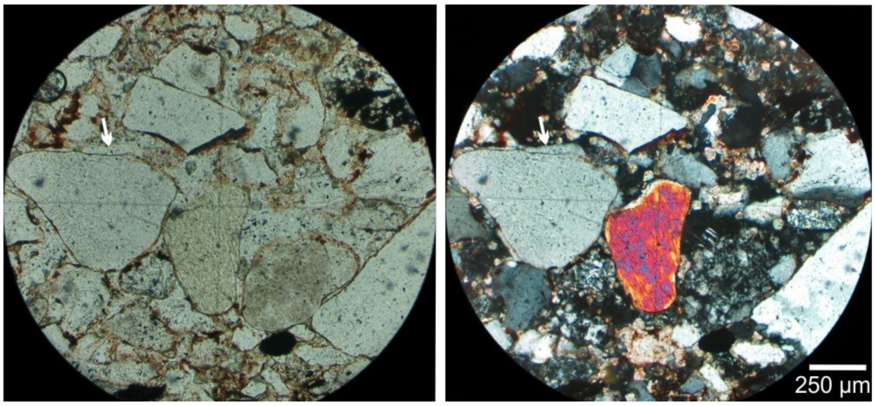

Figure 4 Photomicrograph illustrating the detrital composition of the Rotliegend sandstone. Note the hematite coated anhydrite grain (centre) and quartz overgrowth post-dating hematite coating of quartz grain (white arrow).

2.4 Depositional model

The geological evaluation of the Koekoekspolder geothermal doublet strongly suggests that the Rotliegend sediments were deposited on an aeolian sandflat. Combining all information pertaining to the anhydrite cemented horizons, i.e., lateral extent, thickness, occurrence of detrital anhydrite/gypsum grains it is concluded that the anhydrite cemented horizons were originally gypscretes. Within the sandflat area in the relative low-lying areas, presumably coinciding with the palaeo-lows of the pre-Permian topography, gypscretes were formed as a result of evaporation of groundwater. These gypscretes were subsequently eroded, providing the gypsum grains which form a significant fraction of the coarse grained laminae. The presence of the gypsum is the major cause of the low permeability and hence the poor performance of the doublet.

2.5 Seismic analysis

The Rotliegend sequence was flattened on the palaeo-reference horizontal plane at the top Rotliegend / base Kupferschiefer (Fig. 5). The sequence thickens and thins laterally with a wavelength of 0.5 to 2 kilometer. The seismic shows that pre-Rotliegend palaeo-topography, emphasized by the inclined strata of Carboniferous age below the base of the Rotliegend rocks, governed the lateral thickness variation which is in the order of 40 msec, equalling 30 to 50 meter (Mijnlieff and Geluk 2011). No evidence of Carboniferous rocks was found in the cuttings. Therefore it was concluded that neither well reached the base of the Rotliegend. As no sonic and/or checkshots were run, it is difficult to position the Rotliegend part of the logs in the seismic section. The logs shown in Figure 2 and Figure 5 were converted to the time domain using seismic velocities determined in nearby wells. Especially at the location of the KKP-GT-1 well it appears that the top of the major anhydrite cemented zone correlates with the red to blue seismic signature which fits to the transition of a porous to pervasive anhydrite cemented zone (Figure 5). The large density contrast between the cemented and non-cemented zones is considered to cause a contrast in acoustic impedance, and therefore a strong reflection.

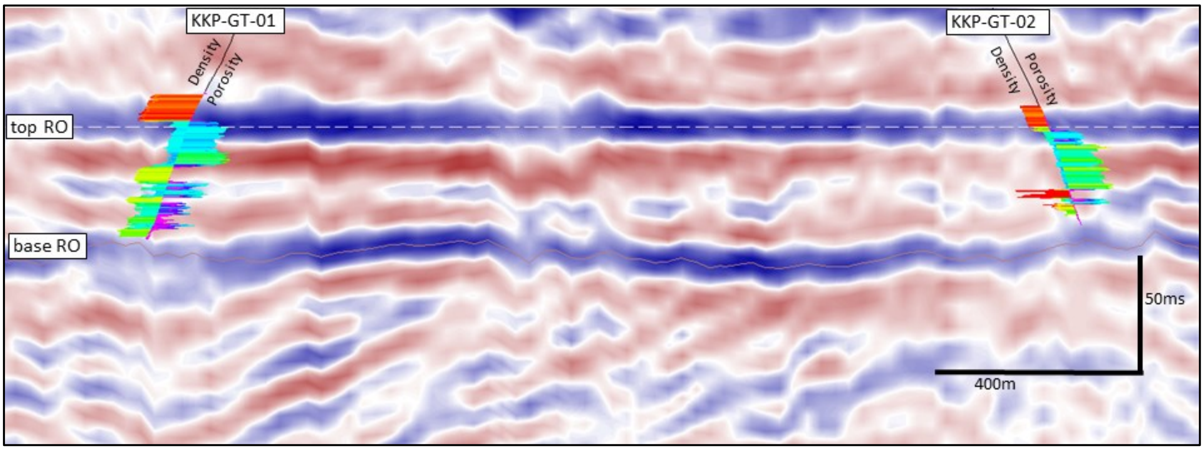

Figure 5 Seismic section through the reservoir between the geothermal wells. The section is flattened on top reservoir. Note that in the KKP-GT-1 and KKP-GT-2 wells base reservoir is not reached. Note the suggestion of seismic response to lithology contrast at the KKP-GT-1 well.

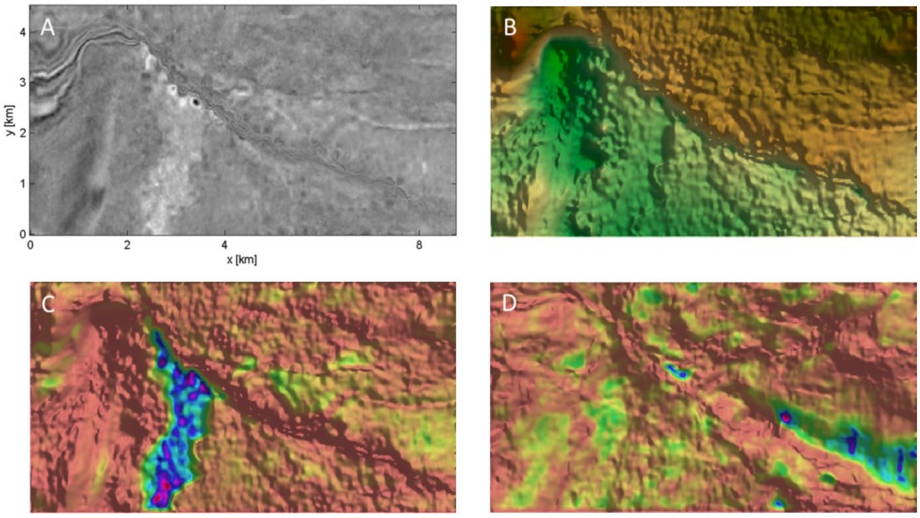

Figure 6 [A] Time slice just below top Rotliegend. Note northwest-southeast running fault. Northeast block downthrown. [B] Illuminated map of seismic terrain height below the flattened horizon. Green=high, orange=low [C] Combined map of illuminated seismic terrain height and the summed reflection strength below the top of the Rotliegend over a 20 msec interval. Red=low, blue/purple=high. [D] as [C] but on non-flattened data.

Variations in signal character can often be tied to geological features. An attempt was made to extract zones of increased reflection strength from the seismic cube using a time-frequency analysis technique described by Van Spaendonck and Steeghs (2003) (Steeghs and Baraniuk, in prep.). Using this technique, dip and slope are determined in the seismic cube in a moving window using the instantaneous auto-correlation. By integrating the local dip and slope, a relief map is obtained (Figure 6 B). The coloured and shadowed relief map provides a great help in interpreting the geology in horizontal slices, as the fringe-like appearance of the seismic reflections shown in A is much harder to translate into 3D relief (Steeghs and Baraniuk). Finally, the reflection strength was summed along the derived relief using a vertical window of 20 msec (Figure 6 C) in the expectation that a pattern of cemented versus non-cemented areas might show up. Indeed, distinct zones of high reflection strenght can be seen in Figure 6 C and D. It is currently not yet understood what the cause of these phenomena is. In the area where both geothermal wells are located (located at approximately 4 km E and, 4 km N), C does not show any distinct features. D, on the other hand, shows a pattern of areas with increased reflection strength measuring several hundreds of meters in length / width, two of which possibly coinciding with the two geothermal wells. The large bright feature in the southeast is thought to be related to the NW-SE running fault. The exact meaning of the pattern is a matter of further research.

CONCLUSIONS

The results of the two new geothermal wells provided additional information to detail the local depositional model to better predict areas of high net reservoir thickness by avoiding abundant anhydrite cemented areas. The refined model will help optimizing well placement for the planned doublets in this area. Attempts to map cemented areas using seismic attribute analysis have yielded results that are not yet fully understood.

ACKNOWLEDGEMENTS

The authors are indebted to the owners of the geothermal wells, represented by mr. Radboud Vorage, for allowing to use the presently confidential data for this study.

REFERENCES

Fryberger, S.G., Knight, R., Hern, C., Moscariello, A. and Kabel, S.: Rotliegend facies, sedimentary provinces, and stratigraphy, Southern Permian Basin UK and the Netherlands: a review with new observations. In: Grötsch, J. and Gaupp, R. (Eds.) The Permian Rotliegend of the Netherlands. SEPM Special Publication 98, (2011), 51-88.

Grötsch, J., Sluijk A., Van Ojik, K., De Keijzer, M., Graaf, J., and Steenbrink, J.: The Groningen gas field: fifty years of exploration and gas production from a Permian dryland reservoir. In: Grötsch, J. and Gaupp, R. (Eds.) The Permian Rotliegend of the Netherlands. SEPM Special Publication 98, (2011), 11–33.

Grötsch, J. and Gaupp, R.: The Permian Rotliegend of the Netherlands. In: Grötsch, J. and Gaupp, R. (Eds.) The Permian Rotliegend of the Netherlands. SEPM Special Publication 98, (2011), 3-7.

Henares, S., Bloemsma, M.R., Donselaar, M.E., Mijnlieff, H.F., Redjosentono, A.E., Veldkamp, J.G. and Weltje, G.J.: Detrital origin of anhydrite lamination in aeolian sandstone, Upper Rotliegend, The Netherlands (in prep).

Ministry of Economic Affairs: Natural resources and geothermal energy in the Netherlands, Annual review, (2012). http://www.nlog.nl.

Mijnlieff, H. F. and Geluk, M.: Palaeotopography-governed sediment distribution - A new predictive model for the Permian Upper Rotliegend in the Dutch sector of the Southern Permian Basin. In: Grötsch, J. and Gaupp, R. (Eds.) The Permian Rotliegend of the Netherlands. SEPM Special Publication 98, (2011), 147–159.

Steeghs, T.P.H. and Baraniuk, R.: Multi-dimensional time-frequency analysis applied to 3-D seismic interpretation. In prep.

Van Spaendonck, R.L.C. and Steeghs, T.P.H.: Time-Slice Topography Using Complex Wavelet Seismic Volume Attributes (2003). 65th Mtg.: EAGE Conference & Exhibition, E37.