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Main controls on natural fracture distribution in the Lower Triassic sandstones of the West Netherlands Basin

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Summary

In this study, a re-evaluation is performed of the well data of the NLW-GT-01 and VAL-01 wells in the Lower Triassic sandstones in the West Netherlands Basin. Core, geophysical and image logs, are compared to document the characteristics of natural fractures distribution, and investigate the geological parameters influencing their development. The main control on the distribution is identified. Natural fractures are concentrated in heterolithic lithological intervals of the VAL-01 and NLW-GT-01 wells. The identification of more fractures in VAL-01 compared to NLW-GT-01 can be explained by the difference in basin location. VAL-01 was located in the centre of the basin where distal playa environments produced fine-grained material alternating with coarser sands. The more proximal NLW-GT-01 was dominated by fluvial sands. The lithological variability produces Young's modulus variability that seems to be driving increased fracture density rather than that the absolute value of the Young's modulus. These fluctuations could be the result of concentrated compressional stress, which is supported by the existence of stylolites, indicative of high compressional stresses in the same intervals. The identification of controls on fracture distribution in the targeted stratigraphic interval can be used to optimize the planning of future geothermal doublets and to de-risk upcoming operations.

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Introduction

In the Netherlands, geothermal energy will provide a significant part of the future energy mix. The Dutch government prepared a plan (EBN 2018) to construct 700 low-enthalpy geothermal doublets by 2050, which requires to reduce the uncertainties in reservoir quality and spatial variability, and to expand the exploration opportunities for future geothermal projects.

This paper focuses on the southern part of the Netherlands, a densely populated area with many industries and greenhouses. In the area of interest, two formations form potentially suitable reservoirs for geothermal production: the Cretaceous Nieuwerkerk Formation and the Triassic Main Bundsandstein Subgroup. These aquifers are well-developed in the so-called West Netherlands Basin (WNB), that is part of a large system of transtensional basins. The WNB was inverted from an extensional regime during the Triassic to a compressional setting in the Late Jurassic by dextral and sinistral transpression. The Main Bundsandstein Subgroup is geologically more complex than the Nieuwerkerk Formation and has a multi-phased diagenetic history (Purvis & Okkerman 1996). The Main Bundsandstein Subgroup was recently explored by the NLW-GT-01 well to evaluate its potential but was not exploited for geothermal energy production due to poor reservoir quality (porosity <5.0%, permeability <0.1 mD, Boersma et al. 2021).

This however does not rule out the potential of this aquifer. In the Upper Rhine Graben, geothermal production is related to natural fractured or enhanced geothermal systems (Vidal & Genter 2018). The impact of natural fractures to unlock geothermal potential of the Main Bundsandstein in the WNB has been studied by Boersma et al. (2021). They concluded that the assumed-to-be open fractures found in the NLW-GT-01 could substantially increase the effective permeability and with that provide sufficient heat production from the Main Bundsandstein in this area. That is supported by potentially open fractures interpreted from image analysis in another well (VAL-01) in the WNB in a study performed by the Atlas Geoscience (1998).

In this study, a re-evaluation is performed of the well data of the NLW-GT-01 and VAL-01 wells. An analysis, comparing core, geophysical and image logs, to document the characteristics of natural fractures distribution in the WNB, and investigate the geological parameters influencing the development of fractures in the Main Bundsandstein Subgroup. The final result is the identification of the main controls behind fracture distribution in the targeted stratigraphic interval, which can be used to optimize the planning of future geothermal doublets and to de-risk upcoming operations.

Data and Methods

To characterize the fracture distribution in the WNB in the Main Bundsandstein Subgroup, an in-depth analysis is performed on two wells: NLW-GT-01 and VAL-01. These are located close to the southern margin and the centre of the basin respectively, as can be seen in Figure 1.

In both wells, an image log and other wireline logs were acquired covering the Main Bundsandstein. In NLW-GT-01, a 30m core is available, covering 5m of the Detfurth and 25m of the Volpriehausen Formation. The VAL-01 well has a 60m core covering 35m of Detfurth and 25m of the Volpriehausen Formation. A core interpretation provides a preliminary assessment of fracture controls, consisting of a complete lithological description, a petrophysical data acquisition, and a detailed structural feature analysis, including a description of discontinuity types, orientation, length, aperture, cementation, relative chronology, and an indication of movement.

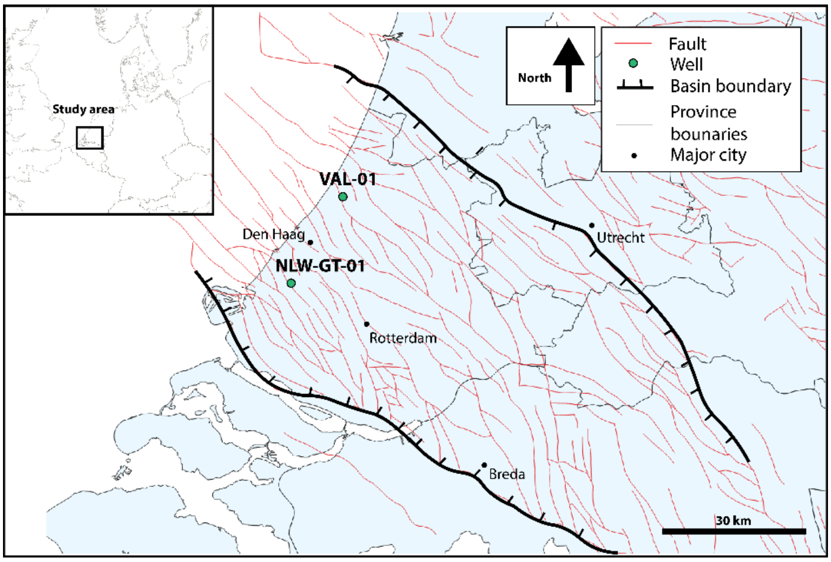

Figure 1 *Fault map of the Lower Triassic in the West Netherlands Basin with location of NLW-GT-01 and VAL-01 (https://www.dinoloket.nl/en/subsurface-models)*

The two image logs are analysed in WellCAD for fracture picking. In the images, high-conductive and low-conductive fractures are distinguished to evaluate the hydraulic conductivity and cementation of the fractures. The core is linked to the image logs and the wireline logs to re-orient the fractures found in the core and extend the fracture analysis to the uncored intervals. Based on the gamma ray, Vp and Vs logs, the shale content, the Poisson's ratio and Young's modulus are obtained to evaluate the lithological variability and the mechanical properties of the formation.

Results

In both cores, three types of fractures are found: extensional fractures and shear fractures that are both cemented by quartz and clay, and stylolites. In Figure 2, three examples of these fractures from the Volpriehausen Formation in NLW-GT-01 can be seen alongside the image log response of the fractures.

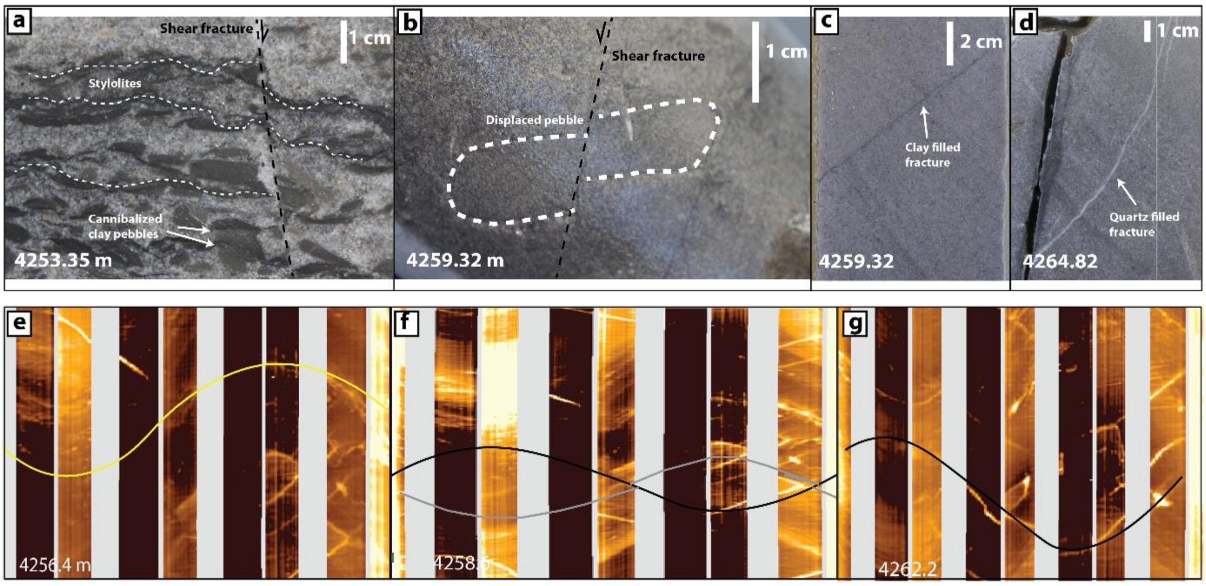

Figure 2 *Fracture types observed in the Lower Triassic formation from the Volpriehausen in NLW-GT-01(4254m-4267m) with the top panels (a-d) displaying the core photographs and the bottom panels (e-g) image logs. Shown are stylolites (a,e), shear fractures (b,f), extensional fractures (c,d,g). Measured depths in the well of the examples are indicated.*

NLW-GT-01

The core from NLW-GT-01 shows very-fine to medium-grained sandstones with minor silt- and claystone intervals and occasional coarser-grained sections that contain clay pebbles. The core shows cross-beddings and cross-laminated sections, that are indicative of a fluvial/aeolian environment. Over the core, 21 extensional fractures, 8 shear fractures and 8 stylolites have been identified. All the stylolites are found in the coarser-grained sections. In the image log, a total of 693 features is recognised from which 156 are straddling the core interval. 53 of these show a full sinusoid and are interpreted as natural fractures. It is striking that the image log shows 16 more interpretable features than the core analysis over the same interval. The non-full sinusoidal features have been interpreted as hydraulically or drilling-induced fractures, similar to the interpretation by Boersma et al. (2020). The natural fractures in the image log only occur in the Volpriehausen Formation in an NW-SE orientation with a 60-90° dip.

There are three intervals where the gamma ray log indicates areas with higher lithological heterogeneity related to the intercalation of silt-claystone beds in the sandstones. Based on the Vp and Vs logs, the geomechanical properties are calculated. The Poisson's ratio varies from 0.1 to 0.3 and the Young's modulus varies between 40 to 80 GPa. There are intervals where the Young's modulus remains fairly constant and sections where there is standard deviation in the variability of 15-20 GPa.

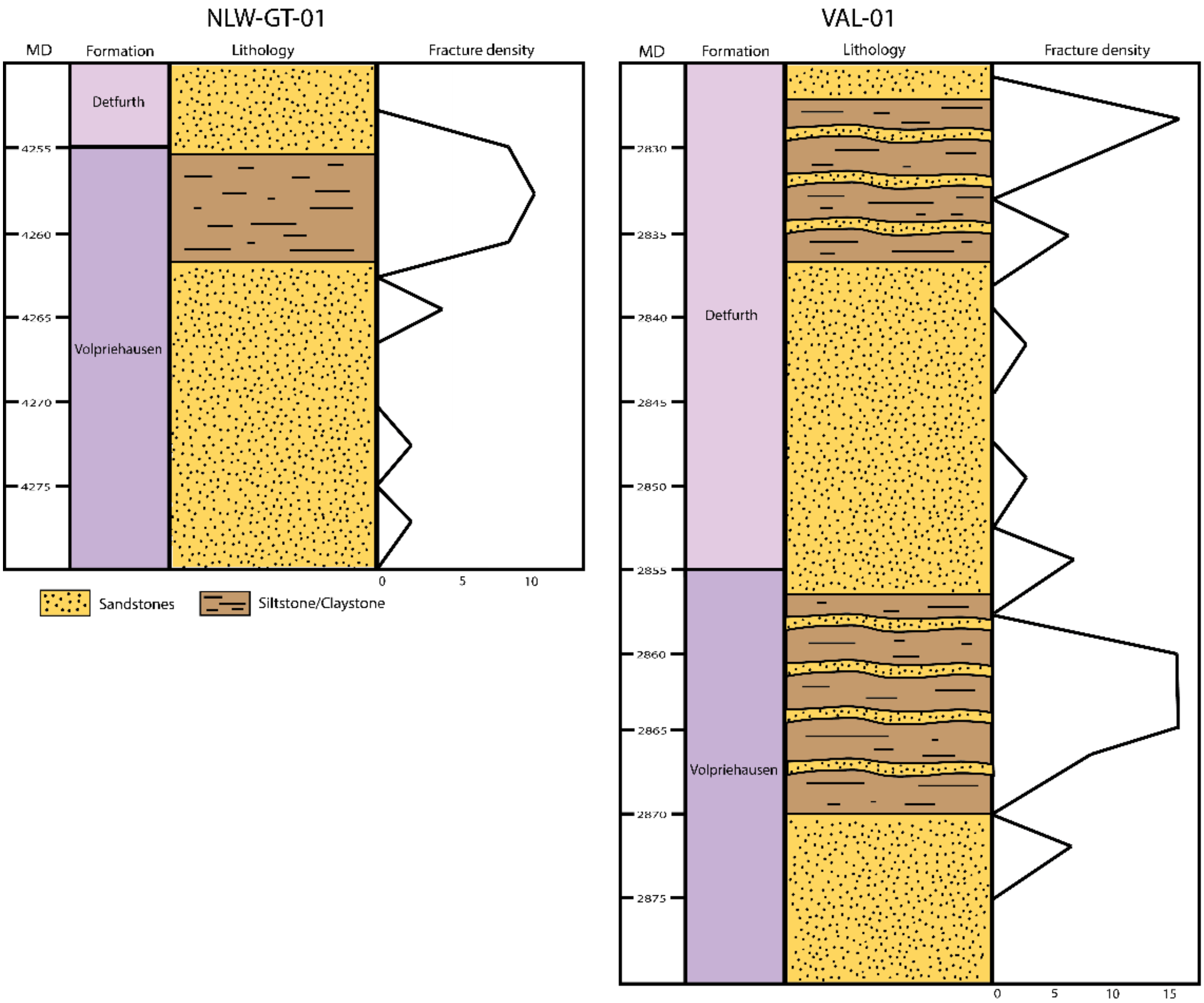

Figure 3 *Schematic overview of fracture distribution and lithology in the core of NLW-GT-01 and VAL-01*

VAL-01

The core from VAL-01 shows very fine to medium-grained sandstones with two clay-rich heterolithic intervals (2828.20-2831.30 m and 2853.70-2669.50 m). The sandstones display cross-bedding and cross-laminated sections. The heterolithic layer is heavily bioturbated, indicative of a more distal environment with playa influences. In the core, 36 extensional fractures, 24 shear fractures and 32 stylolites have been identified. In the image log, 66 full sinusoidal fractures have been interpreted. These have an NW-SE orientation with dip angles between 40-80˚. These findings correspond to the research done by Atlas geoscience (1998). There are some fractures observed in the core, which are below the resolution of the image log. In VAL-01, there are many intervals where the gamma ray log indicates areas with higher lithological heterogeneity.

NLW-GT-01 vs VAL-01

In Figure 3, both wells reveal differences in fracture distribution over the formations. A higher fracture density occurs in both the core and image log of VAL-01, compared to NLW-GT-01. The Detfurth formation shows significantly more fractures in the cores of VAL-01 than in the core of NLW-GT-01. This difference could be partly explained due to a shorter core in NLW-GT-01 and so a less representation of all lithological variability. The Detfurth and Volpriehausen Formations display fractures concentrated in clusters in both studied wells. These fracture clusters are all situated in more heterolithic intervals where the Young's modulus has a standard deviation up to 20 GPA around the mean. This is also the location where the stylolites can be found in the cores.

Discussion and Conclusions

The main control on natural fracture distribution in the Lower Triassic Main Bundsandstein subgroup of the West Netherlands Basin is identified. Natural fractures are concentrated in more heterolithic intervals of the VAL-01 and NLW-GT-01 wells in both image logs and cores. These heterolithic sections display alternations of medium sandstones with silt- and claystones. The identification of more fractures in VAL-01 compared to NLW-GT-01 can be explained by the difference in basin location. VAL-01 was located in the centre of the basin where distal playa environments produced more fine-grained material alternating with coarser sands. The more proximal NLW-GT-01 was dominated by fluvial sands. The lithological variability produces Young's modulus variability that seems to be driving increased fracture density rather than that the absolute value of the Young's modulus causes this. These fluctuations could be the result of concentrated compressional stress, which is supported by the existence of stylolites, indicative of high compressional stresses in the same intervals. **The identification of controls on fracture distribution in the targeted stratigraphic interval can be used to optimize the planning of future geothermal doublet and to de-risk upcoming operations.**

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