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Diagenetic controls on dryland clastic reservoirs from the Buntsandstein Subgroup in the Netherlands

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Summary

The Buntsandstein subgroup in the southeastern part of the Netherlands represents one of the most promising, but risky, geothermal plays. To understand the main controls on Buntsandstein reservoir quality, we combine petrophysical (porosity and permeability) and petrographic (point counting) data derived from different wells and different depth levels. Results show that porosity ranges from 2 to 18.5 and permeability from 0.001 to 285 mD. Dolomite represents the most abundant cement and show an inverse correlation with porosity. Illite occurs in higher concentrations in samples with values of permeability below 20 mD, while kaolinite becomes the most dominant phyllosilicate cement in samples with higher permeability. By looking at the main cement distribution over the sedimentary facies, it appears that dolomite is strongly related to depositional facies and has a positive correlation with grain size, while illite and kaolinite yield a negative correlation with grain size. Pedogenic dolomite nodules are often reworked as detrital grain into the channel scour deposits and are the main source for dolomite cementation. The current study has shown how diagenesis makes Buntsandstein reservoir complex and heterogeneous, and how reservoir quality is strongly related to the depositional environment.

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Introduction

The Lower Triassic Main Buntsandstein Subgroup represents one of the most promising geothermal plays in the Netherlands, with expected temperatures between 80°C and 140°C (Kramers et al., 2012). In the southern part of the Netherlands, reservoir zones consist of several stacked sandstone units deposited in an arid to semi-arid endorheic basin that developed in the early stages of the break-up of Pangea on top of the pre-existing South Permian Basin (Geluk, 2005).

However, as a result of its complex tectonic and digenetic history, Triassic rocks are considered a high-risk target as exemplified by a wide range of measured porosities and permeability (www.nlog.nl). This was further highlighted by a recently drilled geothermal exploration well (NLW-GT-01) targeting the Buntsandstein sediments at depths greater than 4 km. Although the well tests show adequate reservoir temperatures, porosity and permeability were lower than 5% and 0.1 mD respectively, as result of a high degree of compaction and cementation (Felder & Fernandez, 2018).

Dolomite is often described as the main cementing mineral in the Buntsandstein (Maniar, 2019; Veldkamp & Boxem, 2015; Ames, R. & Farfan, 1996). On the other hand, the presence of detrital dolomite has been underestimated in the Lower Triassic of the Netherlands, while many studies have described the importance of the latter in siliciclastic dryland systems, as key element controlling diagenetic evolution, thus reservoir quality (Henares et al., 2016; Molenaar and Felder, 2019) . The current work reports on a comprehensive study of Buntsandstein petrophysical data combined with petrographic data retrieved from different wells in the Roer Valley Graben. These data are integrated with general knowledge about the sedimentology of the Buntsandstein in the study area in order to assess the reservoir quality in the study area and evaluate its major controls.

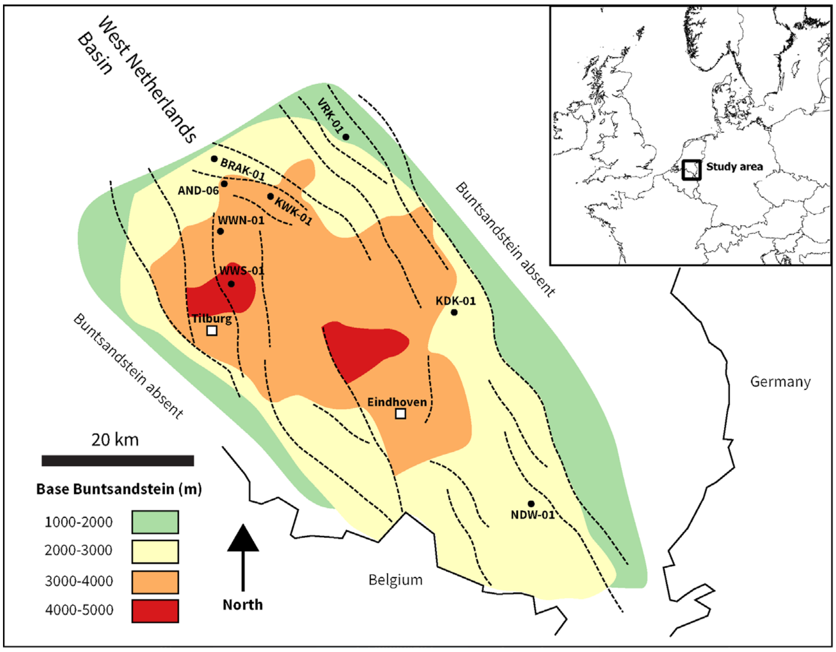

Figure 1: Overview of the study area with well locations and depth of the base of the main Buntsandstein Subgroup

Data and Methods

The dataset includes 67 thin sections from 7 wells, which cover the Buntsandstein stratigraphy at different depths (Fig. 1). For 32 thin sections, qualitative and quantitative data on texture, composition, and interstitial components as cement and matrix were obtained by studying 300 points per section through polarized-light microscope. These data were integrated with a compilation of petrographic data from 35 thin sections of previous studies. The data from these thin sections have been quality controlled before incorporation in the current study. Petrographic data were used to determine the main succession of diagenetic events and then combined with lithological information to evaluate potential relationship with sedimentary facies. Porosity and permeability measurements were derived from publically available industry reports (www.nlog.nl) and used to evaluate major controls on reservoir quality.

Diagenesis

The main porosity-modifying types of cement include dolomite, authigenic quartz, phyllosilicates, and anhydrite (Fig. 2). These cement phases have been encountered in all the wells but in different amounts and textures. In chronological order, the main diagenetic sequence is characterized by the formation of hematite and tangential illite around detrital quartz, followed by the formation of a first phase of dolomite cementing the sandstones (Fig. 2b, c, d & e). Grain coating occurs before any major compaction occurs, as they are continuous at grain to grain contact (Fig. 2e). The presence of point and long contacts in the areas where dolomite cement occurs, suggest the latter to be contemporaneous to compaction (Fig. 2b). Compaction deforms shale fragments creating pseusdomatrix that fills available pore spaces (Fig. 2e). Quartz cement is the next major phase of cementation (Fig. 2d & c), followed by dissolution of feldspars and sedimentary fragments creating secondary porosity (Fig 2a & c). This is followed by a second major cementation phase where kaolinite crystallized within primary and newly created secondary pores, and a second phase of dolomite , siderite, and anhydrite developed (Fig. 2a).

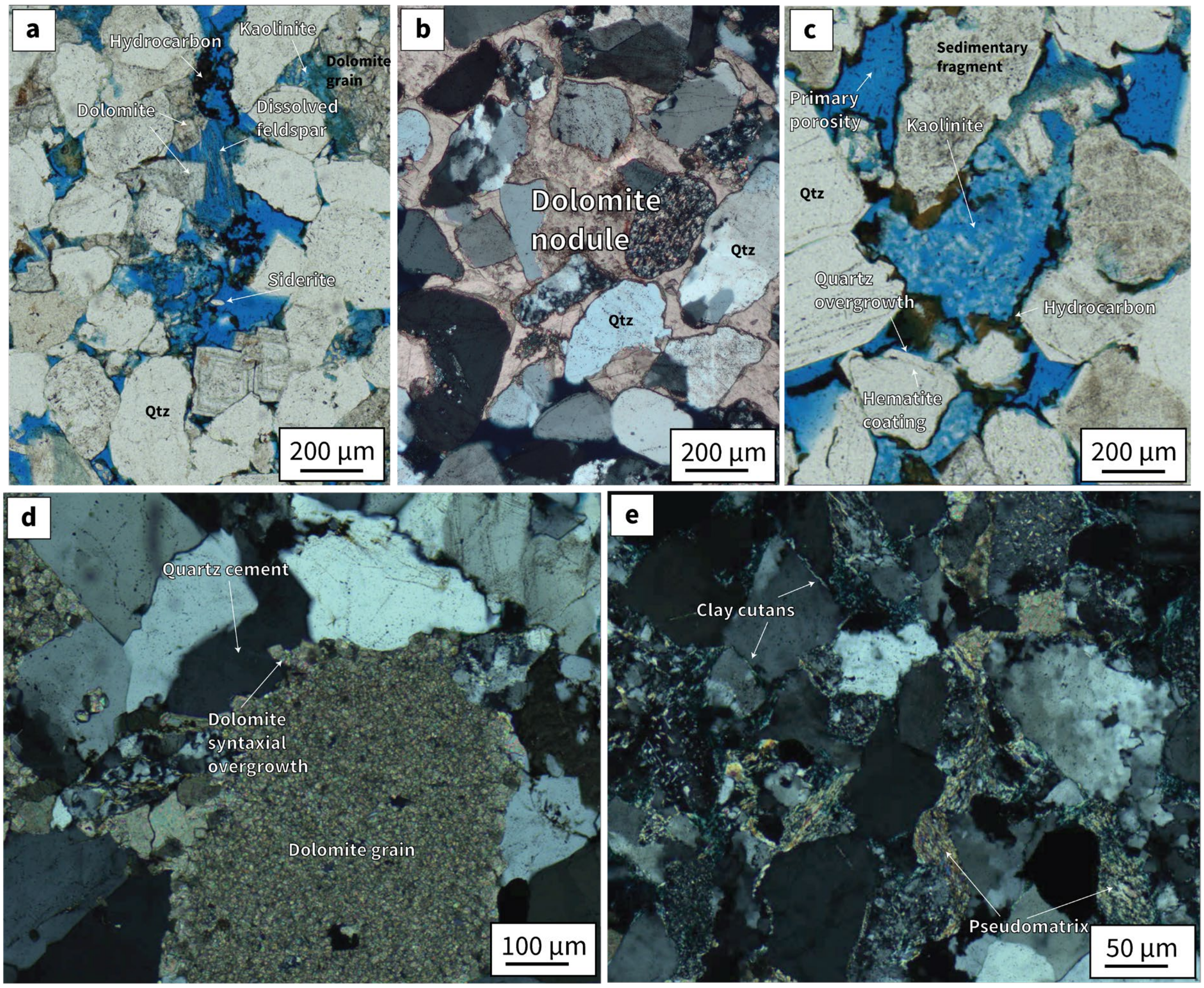

Figure 2: Representative examples of the thin sections analyzed. (A-B-C) images at parallel nicols from VRK-01. Sample depth is 1659.09. (D-E) images at cross nicols from KWK-01. Sample depths are 2550.55 and 2589.70 m.

Diagenetic impact on reservoir quality

The relative abundance of the different types of cement was plotted per sample against permeability and porosity to evaluate key controls on reservoir quality (Fig. 3). The samples studied show porosity ranging from 4 up to 19 %, while permeability ranges from 0.01 to over 100 mD. Overall, dolomite has the strongest control on present-day porosity. Sandstones with a lower porosity tend to have a higher dolomite cement content compared to samples with high porosity, where kaolinite, illite and quartz cement have higher concentration. However, samples with porosity larger than 12% and low content in dolomite cement have a low permeability. This is appears to be linked to high concentration of illite cement, which reaches values over 50% in certain samples. On the other hand, samples where relative content of kaolinite is higher than illite show higher permeability.

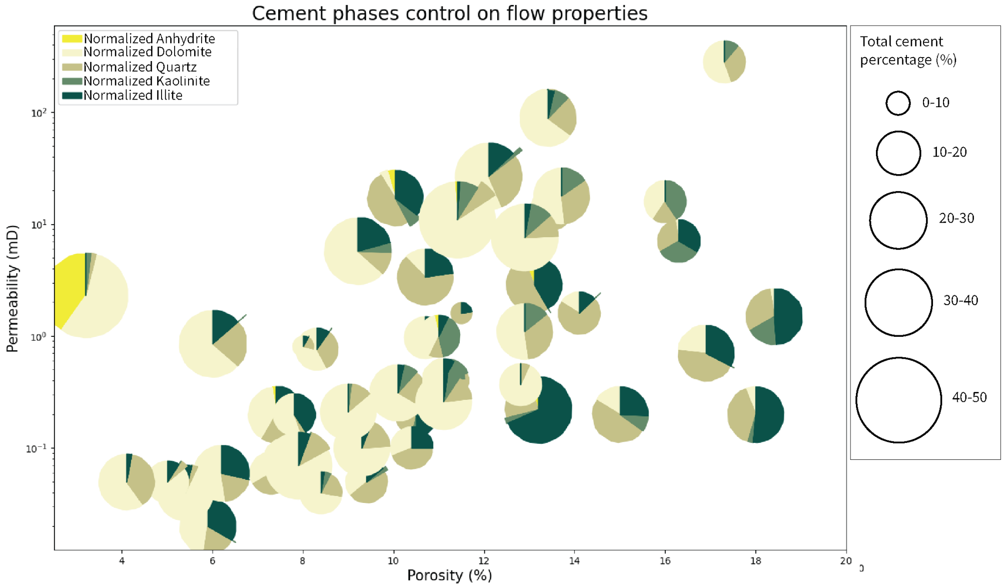

Figure 3: Piechart cross plot showing the influence of cementation groups on porosity and permeability.

Relationship between diagenetic and depositional fabrics

Cementation groups were plotted against Buntsandstein reservoir sedimentary facies to explore the possible relationship with grain size and lithologies. Dolomite is the most dominant cementation phase in conglomerates and coarser sandstones (Fig. 4d), while it is less abundant as the sandstone grain size decreases.

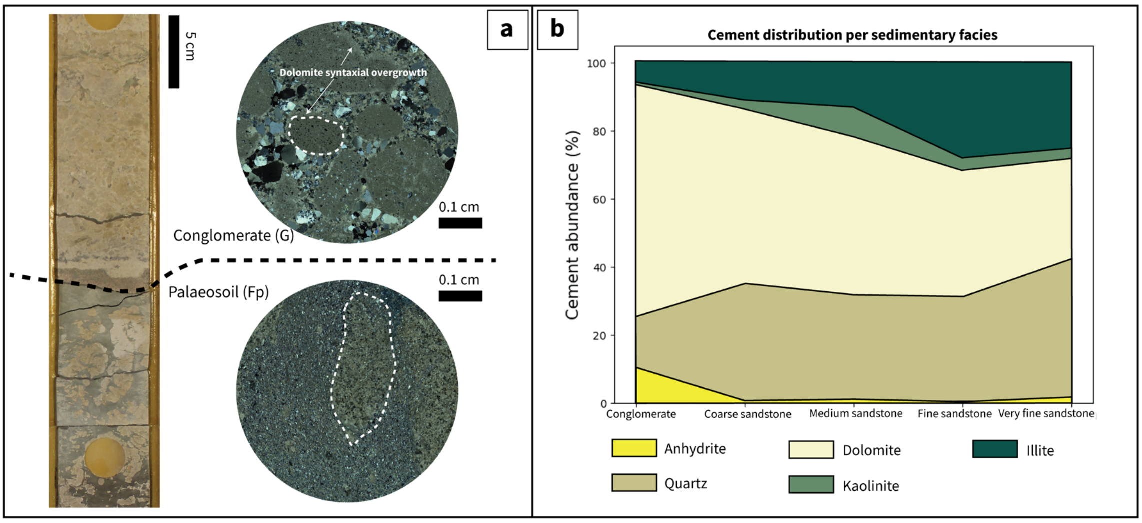

Figure 4: a) Example of a channel scour eroding into older floodplain sediment (palaesoil), well KWK-01. Thin section from palaeosoil show pedogenetic dolomite nodules, which are reworked into the conglomerate above it. These nodules show dolomite syntaxial overgrowth b) Relationship between cementation groups and sedimentary facies.

As grain size decreases, quartz and phyllosilicate cement increase in content. High dolomite cement content in conglomerates and coarser sandstones can be linked to dolomite nodules in the floodplain deposits between fluvial channel sequences and the subsequent reworking of these nodules during channel migration across the alluvial plain (Fig. 4a, b & c). Thereby detrital dolomite clasts are enriched in the lower part of channel sequences and are source for subsequent dolomite cementation. This is something observed frequently in dryland systems and plays a role in predicting reservoir quality (Henares et al., 2016; Molenaar and Felder, 2019).

Conclusion

The occurrence of several primary and diagenetic minerals makes the Buntsandstein Subgroup reservoirs complex and heterogenous. Porosity is strongly inversely linked to dolomite cement. Samples with high porosity are rich in phyllosilicate cement and contain little to no dolomite. These samples are characterized by a relatively low permeability, which can be linked to high content in illite. The latter reduces porosity to microporosity, thus permeability decrease significantly. Conversely, higher content in kaolinite is directly correlated with permeability. While phyllosilicate cement is most abundant in the finer sedimentary facies, dolomite is dominant in the coarser fraction, linked to a higher amount of dolomite detrital gains reworked from the floodplain. The current study has shown that Buntsandstein reservoir quality is strongly related to depositional setting, including the source of sediment grains.

Acknowledgments

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