Leaching of the Triassic: Implications for an underexplored geothermal play in the Netherlands

Introduction

Geothermal energy is a sustainable option for heating, especially in greenhouse agriculture where there is a consistent demand for heat, replacing methane gas. It is also gaining traction in urban areas, such as district heating, exemplified by the TU Delft campus geothermal initiative. The potential of a geothermal reservoir is assessed by its transmissivity, derived from the mathematical product of permeability and net reservoir thickness, and by the reservoir temperature indicative of the available heat.

Present-day reservoir permeability can vary widely due to geological factors, resulting in considerable variations in the permeability of sandstones, sometimes spanning several orders of magnitude. In a basin setting, sequences of burial and uplift can significantly influence primary reservoir properties. Burial often leads to compaction and cementation, which typically reduces pore space and thereby the reservoir permeability. Conversely, uplift can result in leaching, where acidic (meteoric) surface water infiltrates the reservoir rock, dissolving cements and unstable grains. Over time, this process can enhance pore space and reservoir permeability (Gaupp and Okkerman 2011).

This study examines how leaching processes from periods of uplift and erosion have affected the geothermal potential of the Triassic play in the West Netherlands Basin (WNB) and the Roer Valley Graben (RVG), which up to now remains underdeveloped in the Netherlands, having only two geothermal systems in production.

Methodology

This study integrates various data sources to develop a map indicating areas where leaching has potentially enhanced the reservoir quality of the Triassic sandstones for the WNB and the RVG (Figure 1). A top-down approach was employed, beginning with a regional-scale analysis of large structures using a geological model, followed by well-specific examination through petrophysical analysis. Core data from six wells were further described and analyzed to investigate leaching effects at a smaller scale.

The geological leaching model was constructed using descriptive mechanisms from literature, cross-sections from Dinoloket (https://www.dinoloket.nl/), and structural and fault models from previous studies (Kombrink et al., 2012). Well selection was based on this geological model, with well log data, core samples, and cuttings utilized for petrophysical and core data analysis. The results were then integrated with the geological leaching model to generate the leaching map for the WNB and RVG (Figure 1).

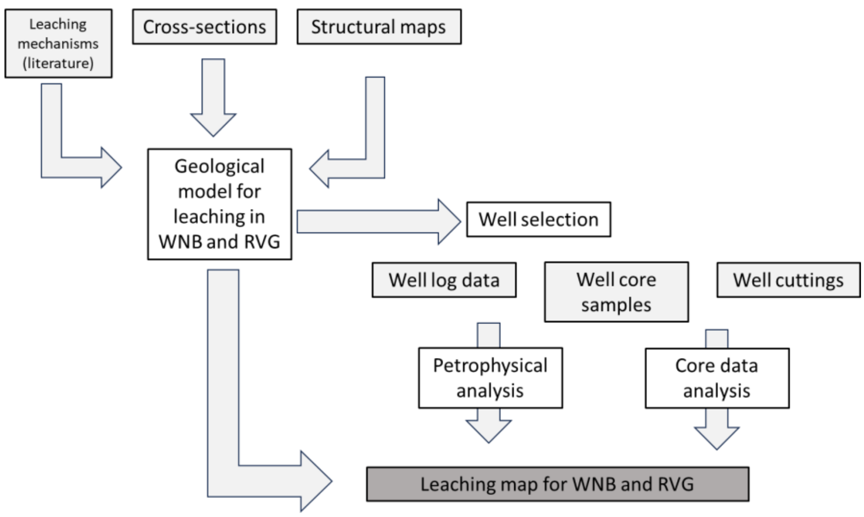

Figure 1 Workflow chart illustrating all the steps taken and data utilized in order to determine the potentially leached areas within the WNB and RVG.

Leaching map for the Triassic reservoirs in the RVG and WNB
Leaching of the Triassic reservoirs occurs when meteoric waters dissolve cements and unstable minerals. This process is restricted to rocks exposed to (or affected by) (near) surface processes. In literature, three structural leaching controls are identified: 1) subaerial leaching, 2) downdip leaching and 3) fault leaching (Figure 2).

These distinct leaching processes occur on a regional scale and can be predicted from geological structures and translated to a geological leaching model. Using the DGMdeep V5 subsurface model this model is illustrated for the WNB and RVG (Figure 2). The cross-sections indicate how and to what extend the different leaching mechanisms can affect the Triassic sandstone reservoirs. Furthermore, these cross-sections demonstrate that most leaching zones are concentrated along the basin fringes, where the Triassic rocks have been most affected by uplift and erosion.

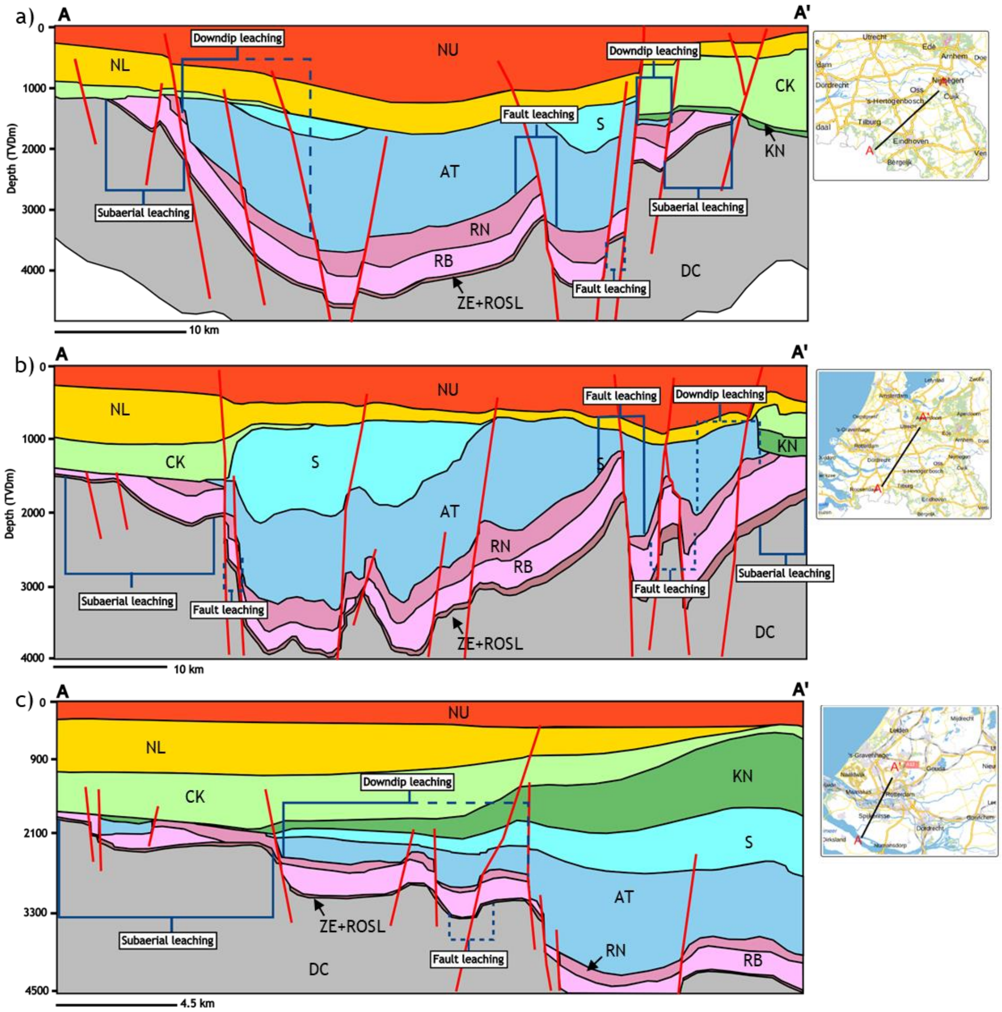

Figure 2. Geological model illustrated with cross sections of the subsurface of the study area. a) SW-NE cross section (Reusel to Grave). b) SW-NE cross section (Breda to Zeist). c) SW-NE cross section (Oudendijk to Berkel en Rodenrijs). The cross sections have been created using TNO-GND Subsurface Model DGMdeep v5.0. The stratigraphical coding is as follows: NU & NL = Upper and Lower North Sea Groups, CK & KN = Chalk and Rijnland Groups, S = Schieland Group, AT = Altena Group , RN and RB = Upper and Lower Germanic Trias Groups, ZE + RO = Zechstein and Rotliegend Groups and DC = Limburg Group.

The effects of leaching on the reservoir quality of the Triassic sandstones is further highlighted by the results from the petrophysical interpretation (Figure 3). The Röt Fringe Sandstone Reservoir and the Main Buntsandstein Reservoir have permeabilities ranging from (min-mean-max) 32-297-1582 mD and 31-268-1512 mD, respectively.

The wide range in average permeability suggests multiple controlling factors, including varying degrees of leaching, burial depth and primary reservoir properties. This is evident in the differences in average permeability between the wells on the southern and northern basin fringes. The combined reservoirs on northern basin fringe exhibit an average permeability of 113 mD whereas those on the southern basin fringe show average permeabilities of 367 mD (Figure 3). These differences in average permeability between the basin fringes are most likely due to significant differences primary reservoir properties such grain size and clay content, as observed from core data. Additionally, the type of leaching plays a significant role, with subaerial leaching being associated with the highest permeabilities.

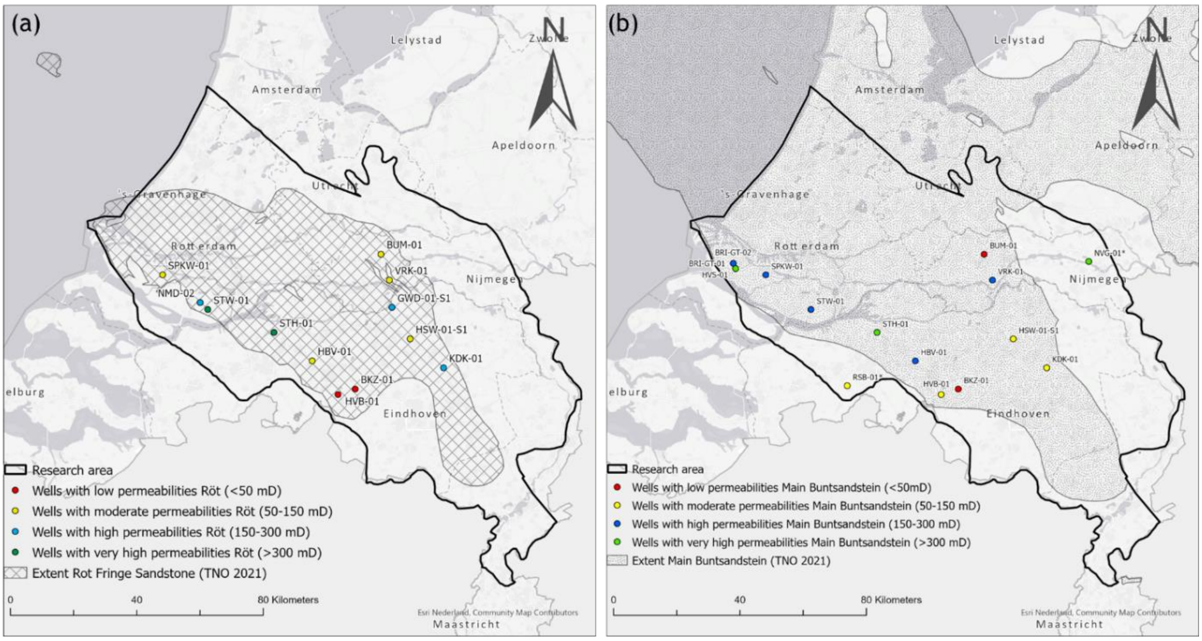

*Figure 3. Permeability results (P50) for all wells. (a) Wells divided in four colour based categories based on P50 permeability results, specifically for the Röt Fringe Sandstone Reservoir. (b) Wells divided in four colour based categories based on P50 permeability results, specifically for the Main Buntsandstein Reservoir. *RSB-01 and NVG-01 are also indicated on this map. However, these wells only contain the Lower Buntsandstein Reservoir. The extend polygons of the RFSR and MBSR are also depicted on the maps.*

Using the geological leaching model and the results from the petrophysical and core-data interpretation, a leaching map for the Triassic play within the RVG and WNB has been created (Figure 4). In these leached zones, it is expected that the reservoir properties of the Triassic sandstones are enhanced. Subaerial leaching has the most positive impact, followed by downdip leaching. Areas affected by fault leaching generally show minor improvements in reservoir quality.

Implications for geothermal energy

Geothermal energy production requires sufficient reservoir transmissivity to be a viable option in the future sustainable energy mix. A transmissivity of 5 Dm is considered the minimum for direct-use geothermal heat production in the Netherlands (Mijnlieff, 2020). This study investigates how leaching processes increase reservoir permeabilities and, consequently, reservoir transmissivities. The findings indicate that due to the high permeabilities attained by leaching, the minimum transmissivity of 5 Dm is commonly surpassed. This suggests that the Triassic sandstones on the basin fringes of the WNB and RVG, particularly the southern fringe, may be viable for geothermal energy exploitation.

Conclusions

Leaching can significantly enhance the porosities and permeabilities of sandstones during periods of exhumation by dissolving carbonate cements and unstable minerals. However, research on the spatial distribution of leaching processes, especially in the context of geothermal exploration, is lacking. This study provides a systematic approach for predicting leaching activity in Triassic reservoirs in the Roer Valley Graben (RVG) and West Netherlands Basin (WNB). Three main types of leaching were identified: subaerial leaching, downdip leaching and fault leaching.

Linking the leaching types to geological structures led to the updated leaching map of Triassic reservoirs within the RVG and WNB. The map indicates that leaching activity is mainly concentrated at the basin fringes, where the best reservoir properties are also found. Therefore, the updated leaching map serves as an indicator for enhanced reservoir quality during geothermal exploration.

While the results of this study can help estimate enhanced reservoir properties caused by leaching in the RVG and WNB, large uncertainties remain, especially on a local scale. Including additional data, such as renewed seismic interpretations in the context of leaching or interpretations of wells positioned more basin inward, can lead to local improvements in the delineation of leached and non-leached zones.

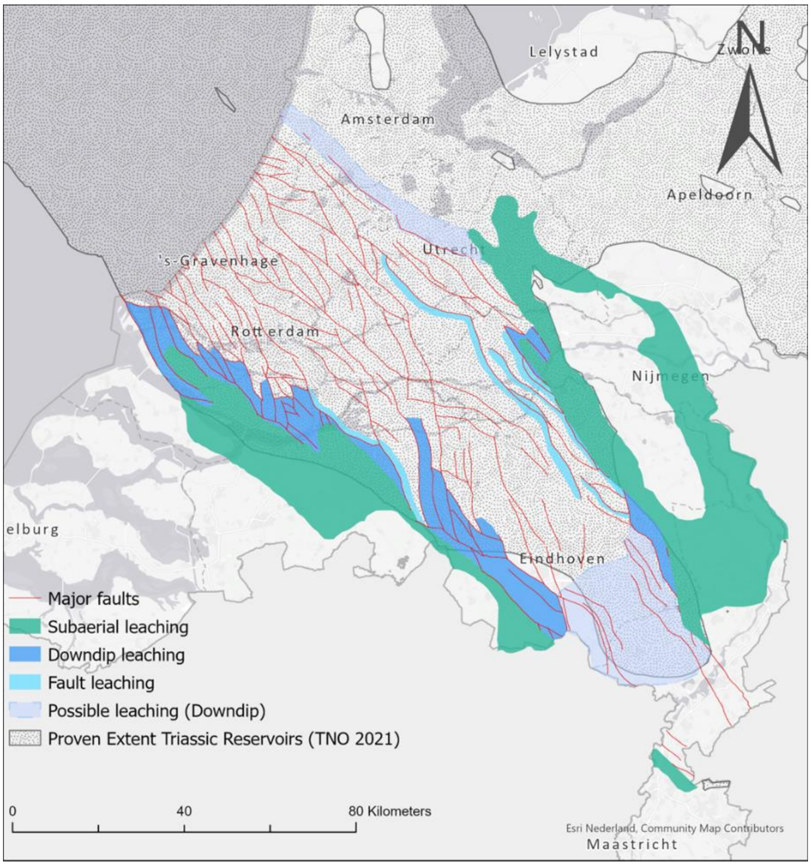

Figure 4. Distribution of the different leaching types for the Triassic play in the RVG and WNB. The map is in part based on platforms (Kombrink et al., 2012) and major Triassic faults. The proven extend of the main Triassic reservoirs (not including LBSR) is indicated by the dotted polygon.

References

Gaupp, R., & Okkerman, J. A. (2011). Diagenesis and reservoir quality of Rotliegend sandstones in the northern Netherlands—a review. SEPM Special Publication, 98, 193-226.

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