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Petrophysical properties of oolitic limestones from the Upper Rhine Graben

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Introduction

In the global context of energy transition, the developement of geothermal energy in the Rhine Graben (France, Switzerland and Germany) represents a major challenge and a significant opportunity to exploit a huge potential of heat/power and associated co-products such as lithium, hydrogen and helium. Over the past few decades, most attention on the georeservoirs of the Upper Rhine Graben (URG) has focussed on deep reservoirs (i.e., the contact zone between basement rocks and first sedimentary cover). However, little attention has been given to potential reservoirs at intermediate depth. Pilot work conducted by the French Geological Survey (BRGM) has suggested that a carbonate formation from the Middle Jurassic (Dogger) may have significant reservoir potential as a target for geothermal energy extraction. This formation, known as the Great Oolite (GO), is present throughout the URG, at depth between 800 to 3100 meters. The highest temperatures, exceeding 100°C, are found where the formation lies deepest and borehole data indicate a geothermal gradient up to 53°C/km in some areas. The primary objective of this study was to map microstructural attributes and petrophysical properties of the GO formation across the entire URG to provide a comprehensive evaluation of its geothermal potential. The second objective was to quantify the possible variations in key properties such as permeability, under in situ conditions.

Studied Material and Method

The GO is an allochemical limestone composed of millimetric carbonate grains (oolites). We collected 40 GO blocks from 8 different outrops in France and Germany. Approximatively 300 cylindral samples (40 mm in length and 20 mm in diameter) were prepared for microstructural analysis, petrophysical measurements (including porosity, P-wave velocity, permeability, electrical and thermal conductivity) using standard methods and high-pressure experiments. Permeability was measured using nitrogen. The higher permeability measurements were performed using the steady-state method, while for lower permeability measurements, the transient pulse method was used. Permeability data were corrected for the effect of fluid flow-related artifacts, turbulent flow (i.e., Forchheimer effect) and/or gas slip along flow channel walls (i.e., Klinkenberg effect). High-pressure measurements were conducted on water-saturated samples, at room temperature, under constant strain rate and at effective pressures of up to 200 MPa.

Results and Conclusions

The porosity of the GO was found between 3 and 30%, while permeability varied between 10^{-18} and 2×10^{-15} m^2. A significant scatter was observed in permeability data, with variations of up to two orders of magnitude at a given porosity. X-ray μCT data revealed a high degree of cementation and limited macroporosity even in samples with high porosity. CT scans also showed significant microstructural heterogeneities, which could account for the observed variability. P-wave velocity and thermal conductivity exhibited less variability and both decreased with porosity in agreement with the models of Raymer-Hunt-Gardner and Maxwell, respectively. High-pressure measurements showed moderate variations in permeability (within one order of magnitude) both in the brittle and ductile regimes, consistent with previous studies on other carbonate rocks. Our new data on intact and deformed GO yielded significantly lower permeability values compared to existing borehole measurements in the same formation. Taken together these results suggest that fractured zones should be prioritized for geothermal exploitation within the GO formation.