Facies and Diagenesis of Rotliegend Geothermal Reservoir Formations (Upper Rhine Graben, Germany): Impact on Thermophysical and Hydraulic Properties

Keywords: Rotliegend, Permocarboniferous, Upper Rhine Graben, outcrop analogue study, geothermal reservoir characterization, diagenesis, thermal conductivity, porosity, permeability

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Abstract

The Permocarboniferous is the largest hydrothermal reservoir in the northern Upper Rhine Graben in SW Germany and has so far been investigated in large scale studies only. Where the Cenozoic Upper Rhine Graben crosses the Permocarboniferous molasse basin of the internal variscides, the top of the up to 2 km thick formation is located at a depth of 1 to 3 km and is overlain by Tertiary and Quaternary sediments. At this depth the reservoir temperatures exceed 150 °C, making it suitable for geothermal electricity generation. To further assess the potential of this geothermal reservoir knowledge of the different lithostratigraphical units and facies types within this former Variscan intramontane basin and their thermophysical and hydraulic properties is essential.

In the present study, a combination of outcrop analogue studies and drill core investigations was conducted. In total 850 outcrop samples were analyzed, measuring porosity, permeability, thermal conductivity and thermal diffusivity. Furthermore, 60 plugs were taken from wells that encountered or intersected the Permocarboniferous in the northern Upper Rhine Graben at depths between 1,800 to 2,900 m. Petrographic analysis of 90 thin sections was conducted to quantify the mineral composition, sorting and rounding of grains, the kind of cementation to determine the type of diagenesis and its influence on porosity, permeability and the degree of compaction.

The strongest influence on reservoir properties exhibit the Hematite-type diagenesis which occurs in early diagenesis and is characterized by grain covering hematite coatings that inhibit cementation of pore space and compaction during diagenesis. In late stage diagenesis the Illit Meshwork-type and Bitumina-type prove CO_2-rich acidic pore water conditions being the result of a hydraulic contact to an underlying Carboniferous oil source rock. Under these conditions the hematite coatings are dissolved and the protection of those sandstones against cementation and compaction are eliminated which led to a strong reduction of porosity and permeability during the second burial phase which took place during the formation of the Upper Rhine Graben. The sandstone´s mineral composition was determined to detect the kind of bedrocks out of which they were formed in order to evaluate them in terms of controlling factors for original sand compositions and its influence on diagenetic processes. Source rock analysis revealed that rocks with the highest contents of quartz are the least vulnerable against diagenetic processes compared to feldspar and mica rich rocks which exhibit granitic source rocks. Best reservoir rock properties were measured for eolian sandstones of the Kreuznach Formation (Upper Nahe Subgroup). Based on these results, reservoir properties of the different Permocarboniferous formations within the northern Upper Rhine Graben and their changes with burial depth and temperature can be predicted with higher accuracy. This leads to a better understanding of the reservoir and enables an adapted approach for exploration and exploitation of the geothermal resources located within this reservoir.