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Fluid flow properties of carbonate rocks under simulated in-situ conditions: Implications for geothermal reservoir quality

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Medium-depth and deep geothermal systems hosted in carbonate rocks are amongst the most promising geothermal resources in the world due to their favorable geological and stress- and temperature-sensitive petrophysical heterogeneity. In general, structural heterogeneities such as natural fractures, karstifications, cavities or entire fracture networks mainly dominate geothermal fluid flows and storages and, thus, dictate the reservoir quality. However, especially for carbonate reservoirs, it is even more complex, as a profound understanding of the links between diagenetic processes, facies, deformations, porosities, and fluid flow properties is essential to estimate the distribution of reservoir quality. This assessment is further complicated by the spatially and temporally varying pressure and temperature conditions (e.g., recharge and discharge of geothermal systems).

In the wake of Bavaria's (southern Germany) success story in exploiting the geothermal systems hosted in deep carbonates, there are extensive investigations to determine the geothermal potential of Devonian carbonates in North Rhine-Westphalia (western Germany). The geothermal potential of these Devonian carbonates strongly depends upon how and to what extent the tectonically influenced burial history and diagenetic processes have modified the pore network and promoted heterogeneities such as fractures and karstifications. In our triaxial experiments, we examined the influence of in-situ stress and temperature and their histories as well as the influence of brittle faulting on porosities and hydraulic properties of different Devonian carbonate rocks. From analogue outcrops limestone, dolomitic limestone, dolostone, and fractured carbonates were sampled and petrophysically investigated. The stresses simulated covered both hydrostatic and triaxial states. Furthermore, the influence of elevated temperature and stress on the hydraulic properties of samples triaxially compressed at effective confining pressures was also studied systematically. Our results show that the interplay of temperature and stress state, and their histories, are fundamental for the evolution of hydraulic properties in the reservoir. Depending on the rock's mineralogy, the mineral expansion caused by the increased temperature can surpass the effect of microcracking due to heating, resulting in a significant decrease in hydraulic properties. Our results were supplemented by micro-CT images of the microstructure of the samples before and after triaxial testing. It is shown that the interaction of temperature and stress is fundamental for the assessment of the geothermal potential of both intact and fractured carbonate reservoirs.