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Fault zones in Triassic Muschelkalk limestones of the Upper Rhine Graben: Infrastructure characterization and permeability structure analyses

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The characterization of fault zones is of particular importance in geothermal reservoirs since there may be great effects on fluid flow. Fault zones generally consist of two major hydromechanical units: the fault core and the damage zone, surrounded by the unaffected host rock. To improve predictions of fracture system parameters for each unit and resulting estimations of reservoir permeabilities at depths, we perform outcrop analogue studies. We analyze Middle Triassic Muschelkalk limestones that form one potential geothermal reservoir formation in the Upper Rhine Graben (URG), in quarries on its eastern graben shoulder.

We measure the orientations and displacements of various fault zones and characterize the fracture systems within the fault zone units and the host rock. Important features in terms of reservoir permeability are the fracture aperture, the fracture connectivity and the fracture vertical extension. Fractures have to be connected to create a hydraulically relevant flow path and non-stratabound fractures could create a hydraulic connectivity between multiple layers.

We observed a decreasing fracture length with increasing distance to the fault core but a better connectivity between shorter fractures in the well-developed damage zones. Our studies show, however, that the differing mechanical properties in the analyzed limestone-marl alternations are significant for the fracture propagation, even in the fault zones.

Based on the field data we use analytical models to estimate the permeabilities of the analyzed fracture systems. Results show increased fracture frequencies in the fault zone damage zones and larger fracture apertures parallel or subparallel to fault zone strike and to the URG that lead to enhanced permeabilities compared with other fracture orientations. Mineralized fractures accumulated in directions parallel or subparallel to fault zone strike as well as observed mineralizations in some fault cores indicate a fluid flow along the fault zones in the past. This shows that open fractures with orientations parallel to fault zones may be pathways for fault zone parallel fluid flow in geothermal reservoirs. By contrast, the well-developed fault cores, comprising fault gouge, fault breccia and host rock lenses, may be potential barriers for fluid flow in inactive fault zones.

It is concluded that the fault damage zones in Muschelkalk limestones are potential drilling targets of geothermal wellbores in the URG. Hydraulic stimulation may be required, however, to improve the connectivity of the natural fracture network. The presented studies help to predict the permeability of fault-related geothermal reservoir rocks and minimize the exploration risk of geothermal projects.

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