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Natural fracture permeability in Triassic sediments of the Upper Rhine Graben from deep geothermal boreholes

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Geothermal anomalies (Soultz-sous-Forêts, Rittershoffen, Landau, . . .) in the Upper Rhine Graben (URG), are mainly interpreted as the effect of natural brine advection inside a nearly vertical fracture network extending from the deep-seated Triassic sediments to the crystalline basement. At Soultz, within the first kilometer of sediments, where the temperature reaches up to 110°C, the dominating thermal regime remains conductive. Accordingly the fracture system in this region, made of normal faults, does not have a significant impact on temperature profiles. Deeper, in the clastic sediments and in the crystalline basement, a convective regime is evidenced by a reduction of the effective geothermal gradient (∼10°/km) and localized negative thermal anomalies that match with the occurrence of natural fractures. The aim of this study is to contribute to a better understanding of the top of the convective cell structure based on a combined analysis of borehole geothermal logs recorded around the sediment/basement interface.

The first part consists in analyzing geological and geophysical data available from the Soultz wells which characterize the natural permeability: partial or total drilling mud losses, natural outflow, occurrences of Helium gas and drilling mud temperature variations. A series of eleven permeable fracture zones has been outlined in GPK-2, GPK-3 and GPK-4 wells. Within the Muschelkalk limestones, 3 fracture zones are located in GPK-2, 2 in GPK-3 and 3 in GPK-4 respectively. In the Buntsandstein sandstones, a total of 8 zones were detected in GPK-2, GPK-3 and GPK-4. In GPK-2, less than 50% of the detected zones are permeable, in GPK-3, more than 80% and in GPK-4, 100% but the thermal impact of those fracture zones is not clearly visible on temperature profiles.

To support those results, geophysical logs and mud logging data of the sedimentary part of GPK-1 were spatially correlated. Two fracture zones have been located in the Keuper and Lettenkohle, two in the Muschelkalk and nine in the Buntsandstein. All the thirteen zones present permeability indicators.

In the EPS-1 well, partial mud losses recorded at a depth of 1205m, match with the occurrence of a fracture zone within the Buntsandstein. BHTV images show that the fracture is N-S oriented and dipping westward. Core samples of this zone show that it is partly filled with barite and galena. In the 4550 well, total losses were recorded at a depth of 1280m in Buntsandstein which fits in depth with a fracture zone. BHTV images clearly exhibit the westward dipping of the conjugate small-scale fracture system. Interestingly it corresponds to a sharp negative thermal anomaly on the temperature profile.

In the Soultz and Rittershoffen areas, the uppermost sedimentary domain extending from late Trias to Tertiary is rather impermeable and governed by a conductive thermal regime. The uppermost structure of the convective cell corresponds to hydrothermal circulations percolating within the vertical fracture network from the top of the Paleozoic granite basement, to the Muschelkalk through the fractured Buntsandstein. The Keuper is assumed to be a horizontal barrier to the vertical per ascensum convective flow and behaves as a geothermal cap rock.