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A multi-tracer approach for the exploration of deep geothermal energy potential and fault zone characterisation, applied in the Upper Rhine Graben

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Current methods of geothermal exploration rely on various expensive geophysical methods (e.g. 3D reflection seismics) to identify permeable fault zones and the geometry of geothermal aquifers. However this analysis alone does not allow for an estimation of an active fault's hydraulic permeability nor provides a characterisation of the chemical properties of the deep aquifer fluid. Both factors play an important role in optimising siting of geothermal wells and operation of a geothermal power plant.

This work presents a low cost strategy characterizing deep hydrogeochemical reservoirs using a combination of methods from hydrogeochemistry and isotope hydrology in hot springs and near surface groundwater. The main goal is to confine the area of interest for further, indirect geophysical investigation. For this purpose natural geochemical and isotopical tracers as well as rare earth elements, $^{3}He/^{4}He$ ratios, and radiogenic isotopes (Sr and Pb) are investigated.

Data from the first sampling campaign in the northern Upper Rhine Graben, close to Groß-Gerau, Germany, shows promising results, indicating an area of increased interest where elevated helium ratios coincide with characteristic geochemical data, fault location and a previously known saltwater anomaly. Geochemical analyses exhibit three different types of fluids and various mixtures. $CaHCO_3$-dominated waters represent Quaternary aquifer conditions whereas $MgSO_4$-dominated waters are characterised by a Tertiary aquifer rock. Higher saline NaCl-dominated waters show an impact of mantle fluids revealed by $^{3}He/^{4}He$ isotope analysis. The ratio is highest where the main fault of the northern Upper Rhine Graben crosses the Rhine river. This suggests that the fault is hydraulically active and connects ascending deep fluids with the shallow aquifer.

Further investigations of rare earth element patterns as well as radiogenic isotopes will identify the origin, the ascent as well as the retention time of the deep fluids more precisely. Water-rock interactions and mixtures of different fluids in the reservoir and during the ascent are estimated and simulated using geochemical and hydraulic models. Thus, the geometry of the aquifer, the temperature, the quantity and the quality of the ascending deep fluid in the reservoir is estimated. The retention time is a good indicator for the deep fluid being part of a fossil reservoir or being recharged naturally. The Upper Rhine Graben was chosen to test the multi-tracer method due to its well-studied geology and some significant preexisting geophysical data to allow for comparison and validation of the study's findings. The aim is to identify the most useful tracers of deep geothermal fluid circulation, which consecutively can be applied to other regions with less prior information.