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Groundwater circulation and heat transport in the crystalline basement – two numerical models and their interpretation

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The characteristics of deep groundwater flow and heat transport in crystalline rocks represent a challenging field of study. Due to their low permeability ($k_f < 10^{-8}$ m/s) these rocks are only of minor importance for groundwater exploration and for that reason there is only little geological data gained from drillings or other investigations. This is notably true for the granites and gneisses of the Black Forest in SW Germany. But here, thermal springs and wells at the Upper Rhine Graben border fault to the East reveal the extent of the actual heat and water transport through the basement. Methods like numerical modeling can be applied to gain more knowledge on the formation, motion, and behaviour of these thermal waters.

Using the finite element software FEFLOW®, fully coupled flow and heat transport models have been set up for the localities of Baden-Baden and Ohlsbach. Baden-Baden is a famous spa with a long tradition of thermal water usage. The natural springs have temperatures of up to 67 ˚C and together with two thermal wells they produce 820 m^3/d. Another thermal resource is located near Ohlsbach in the Ortenau district. The upwelling thermal waters here are of lower temperature (today 18˚C) and do not reach the surface. They intrude into the Quarternary valley sediments and flow within these layers towards the river Rhine in the East. At both localities the thermal waters are highly mineralized.

The numerical simulations include the steady-state three-dimensional groundwater flow as well as the conductive and convective heat transport. Supported by a recently developed module, it is possible to couple both density and viscosity of the circulating fluid to the temperature. This temperature dependence of fluid properties allows free convection of the thermal waters and is therefore a crucial factor for an accurate numerical model of the deep crystalline circulation. The simulations result in a better understanding of flow velocities, hydraulic conductivities, travel times, temperature distribution, and upwelling characteristics. The dependencies of all parameters have been investigated by sensitivity studies.

Both 3D models, Ohlsbach and Baden-Baden, have been set up using the same methods and simplifications. The results can thus be compared to distinguish local factors from general principles of the circulation mechanisms. One main principle which both localities have in common is the significant influence of faults and fissured zones close to the Upper Rhine Graben border on the upwelling characteristics. More models are being developed to increase the number of comparable results and thereby the reliability of the studies.