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Internal structure of the Aar Massif: What can we learn in terms of exploration for deep geothermal energy?

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The successful use of deep geothermal energy requires 3D flow paths, which allow an efficient heat exchange between the surrounding host rocks and the circulating fluids. Recent attempts to exploit this energy resource clearly demonstrate that the new technology is facing sever problems. Some major problems are related to the prediction of permeability, the 3D structure of the flow paths and the mechanical responses during elevated fluid pressures at depths of several kilometers. Although seemingly new in a technical perspective, nature is facing and solving similar problems since the beginning of the Alpine orogeny.

Based on detailed studies in the Hasli Valley (Aar Massif) we can demonstrate that deformation and fluid flow are strongly localized along mechanical anisotropies (e.g. lithological variations, brittle and ductile faults). Some of them already evolved during Variscan and post-Variscan times. Interestingly, these inherited structures are reactivated over and over again during the Alpine orogeny. Their reactivation occurred at depths of ~13-15 km with elevated temperatures (400-475°C) and involved both ductile and brittle deformation processes. Brittle deformation in form of hydrofracking was always present due to the circulating fluids. It is this process, which was and still is responsible for seismic activity. With progressive uplift and exhumation of the Aar Massif, ductile deformation structures became replaced by brittle cataclasites and fault gouges during fault activity at shallower crustal levels. Existing hydrotest data from the Grimsel Test Site (Nagra's underground research laboratory) indicate that these brittle successors of the ductile shear zones are domains of enhanced recent fluid percolation. Note that although being exposed today, the continuation of these fault structures are still active at depth in both brittle and ductile deformation modes, a fact that can be inferred from recent uplift rates and the active seismicity. On the scale of the Aar Massif, the aforementioned deformation sequence induced a complex and dense network of large-scale fault zones. The 3D structure of this network and the associated spacing between the individual faults strongly depends on the type of host rock, intensity of background strain and the location (kinematics) within the massif. Similar effects have to be expected in the crystalline rocks underneath the sedimentary cover in Northern Switzerland. However, based on the aforementioned findings, several facts might be in favor for future exploration of deep geothermal energy in the Aar Massif: (i) enhanced permeability in brittle fault rocks, (ii) dense 3D network auf brittle faults, (iii) weak vegetation allows a reliable projection of the structures to depth as well as tracking of their lateral continuation (crucial for estimates on seismic potential) and last but not least the existence of an elevated geothermal gradient.