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Experimentally derived permeability of fault zones in a fractured and faulted carbonate aquifer

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Deformation along faults in the shallow crust introduces permeability heterogeneity and anisotropy, which has an important impact on regional groundwater flow. Fault zones typically include one or several fault cores with different fault rocks and fractured damage zones with variable fracture density and fracture anisotropy. Faults have the capacity to be hydraulic conduits connecting shallow and deep geological environments, but simultaneously the fault cores of many faults may form effective barriers to flow.
The direct evaluation of the impact of faults to fluid flow expressed by the permeability of the different parts of a fault zone (fault core and damage zones) is challenging and requires a multidisciplinary research effort combining structural geology techniques and hydrogeological methods. This is due to the fact that conventional bench-top permeability measurements using plug-size rock samples are restricted to volumes, which are much smaller than the representative elementary volumes of fractured rock in the damage zones, although these zones play the major role in groundwater storage and flow (Bauer et al., 2016, Hydrogeology Journal). Borehole test, on the other hand, typically cannot differentiate between the different parts of a fault zone penetrated at depth.
Our study therefore focuses on the establishment of a simple field-based technique for the in situ determination of permeability in the different parts of fault zones. The method was tested and validated in low-porosity Triassic dolostones and limestones of the Hochschwab Massif in the Austrian Northern Calcareous Alps. The fractured and faulted karstic aquifers of this region supply about 60% of the Vienna water usage.
The hydraulic conductivity of different parts of a fault zone is determined in situ using small scale injection tests. The novel tests are performed in boreholes with up to about 0.9 m length and a diameter of 0.01 m. By their dimension, such boreholes cover representative elementary volumes of fractured rocks in fault cores. They are, on the other hand, small enough to charascterize different parts of the damage zones without levelling over parts of the fault with different hydraulic properties. Pioneer tests carried out on three fault zones in limestone, dolostone and a fault contact between limestone and dolostone revealed differences between the hydraulic conductivities of parts of the fault zones that range over 4 orders of magnitude (10-9 to 10-5 m/s). These values correspond to permeabilities ranging from < 1mD to about 1 D.
The results prove that the injection test is a suitable method to measure hydraulic conductivity. Test results are partly validated by benchtop measurements of permeability and the comparison of the laboratory result with in-situ measurements. However, further validation is required to prove the reliability of the results.