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Large-scale hydraulic structure of a seismogenic fault at 10 km depth (Gole Larghe Fault Zone, Italian Southern Alps)

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The definition of hydraulic properties of fault zones is a major issue in structural geology, seismology, and in several applications (hydrocarbons, hydrogeology, CO_2 sequestration, etc.). The permeability of fault rocks can be measured in laboratory experiments, but its upscaling to large-scale structures is not straightforward. For instance, typical permeability of fine-grained fault rock samples is in the 10-18-10-20 m2 range, but, according to seismological estimates, the large-scale permeability of active fault zones can be as high as 10-10 m2. Solving this issue is difficult because in-situ measurements of large-scale permeability have been carried out just at relatively shallow depths - mainly in oil wells and exceptionally in active tectonic settings (e.g. SAFOD at 3 km), whilst deeper experiments have been performed only in the stable continental crust (e.g. KTB at 9 km). In this study, we apply discrete fracture-network (DFN) modelling techniques developed for shallow aquifers (mainly in nuclear waste storage projects like Yucca Mountain) and in the oil industry, in order to model the hydraulic structure of the Gole Larghe Fault Zone (GLFZ, Italian Southern Alps). This fault, now exposed in world-class glacier-polished outcrops, has been exhumed from ca. 8 km, where it was characterized by a well-documented seismic activity, but also by hydrous fluid flow evidenced by alteration halos and precipitation of hydrothermal minerals in veins and along cataclasites. The GLFZ does not show a classical seal structure that in other fault zones corresponds to a core zone characterized by fine-grained fault rocks. However, permeability is heterogeneous and the permeability tensor is strongly anisotropic due to fracture preferential orientation. We will show with numerical experiments that this hydraulic structure results in a channelized fluid flow (which is consistent with the observed hydrothermal alteration pattern). This results in a counterintuitive situation where a permeable fault zone act as a barrier to fluid flow.