Permeability contrasts of fault zones - from conceptual model to numerical simulation

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Fault and fracture networks can govern fluid flow patterns in the subsurface and predicting fluid flow on a regional scale is of interest in a variety of fields like groundwater management, mining engineering, energy, and mineral resources. Especially the pore fluid pressure can have a strong impact on the strength of fault zones and might be one of the drivers for fault reactivation. Reliable simulations of the transient changes in fluid pressure need to account for the generic architecture of fault zones that comprises strong permeability contrast between the fault core and damage zone.

Particularly, the distribution and connectivity of large-scale fault zones can have a strong impact on the flow field. Yet, modelling numerically such features in their full complexity remains challenging. Often faults zones are conceptualized as forming exclusively either barriers or conduits to fluid flow. However, a generic architecture of fault zones often comprises a discrete fault core surrounded by a diffuse damage zone and conceptualizing large scale discontinuities simply as a barrier or conduit is unlikely to capture the regional scale fluid flow dynamics. It is known that if the fault zone is hosted in low-permeability strata, such as clays or crystalline rocks, a transversal flow barrier can form along the fault core whereas the fracture-rich fault damage zone represents a longitudinal conduit. In more permeable host-rocks (i.e. sandstones or carbonates) the reverse situation can occur, and the permeability distributions in the damage zones can be governed by the abundance of low-permeability deformation features. A reliable numerical model needs to account for the difference and strong contrasts in fluid flow properties of the core and the damage zone, both transversally and longitudinally, in order to make prediction about the regional fluid flow pattern.

Here, we present a numerical method that accounts for the generic fault zone architecture as lower dimensional interfaces in conforming meshes during fluid flow simulations in fault networks. With this method we aim to decipher the impact of fault zone architecture on subsurface flow pattern and fluid pressure evolution in fractures and faulted porous media. The method is implemented in a finite element framework for Multiphysics simulations. We demonstrate the impact of considering the more generic geological structure of individual faults on the flow field by conceptualizing discontinuities either as barriers, conduits or as a conduit-
barrier system and show where these conceptualizations are applicable in natural systems. We further show that a reliable regional scale fluid flow simulation in faulted porous media needs to account for the generic fault zone architecture. The approach is finally used to evaluate the fluid flow response of statistically parameterised faulted media, in order to investigate the impact and sensitivity of each variable parameter.