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# Modelling Fault Zone Evolution: Implications for fluid flow.

H. Moir (1), R. J. Lunn (1), and Z. K. Shipton (2)

(1) University of Strathclyde, Civil Engineering, Glasgow, United Kingdom (heather.moir@strath.ac.uk), (2) Department of Geographical and Earth Sciences, University of Glasgow, Scotland

Flow simulation models are of major interest to many industries including hydrocarbon, nuclear waste, sequestering of carbon dioxide and mining. One of the major uncertainties in these models is in predicting the permeability of faults, principally in the detailed structure of the fault zone.

Studying the detailed structure of a fault zone is difficult because of the inaccessible nature of sub-surface faults and also because of their highly complex nature; fault zones show a high degree of spatial and temporal heterogeneity i.e. the properties of the fault change as you move along the fault, they also change with time.

It is well understood that faults influence fluid flow characteristics. They may act as a conduit or a barrier or even as both by blocking flow across the fault while promoting flow along it. Controls on fault hydraulic properties include cementation, stress field orientation, fault zone components and fault zone geometry. Within brittle rocks, such as granite, fracture networks are limited but provide the dominant pathway for flow within this rock type. Research at the EU's Soultz-sous-Foręt Hot Dry Rock test site [Evans et al., 2005] showed that 95% of flow into the borehole was associated with a single fault zone at 3490m depth, and that 10 open fractures account for the majority of flow within the zone. These data underline the critical role of faults in deep flow systems and the importance of achieving a predictive understanding of fault hydraulic properties.

To improve estimates of fault zone permeability, it is important to understand the underlying hydro-mechanical processes of fault zone formation. In this research, we explore the spatial and temporal evolution of fault zones in brittle rock through development and application of a 2D hydro-mechanical finite element model, MOPEDZ. The authors have previously presented numerical simulations of the development of fault linkage structures from two or three pre-existing joints, the results of which compare well to features observed in mapped exposures. For these simple simulations from a small number of pre-existing joints the fault zone evolves in a predictable way: fault linkage is governed by three key factors: Stress ratio of s1 (maximum compressive stress) to s3(minimum compressive stress), original geometry of the pre-existing structures (contractional vs. dilational geometries) and the orientation of the principle stress direction (1) to the pre-existing structures.

In this paper we present numerical simulations of the temporal and spatial evolution of fault linkage structures from many pre-existing joints. The initial location, size and orientations of these joints are based on field observations of cooling joints in granite from the Sierra Nevada. We show that the constantly evolving geometry and local stress field perturbations contribute significantly to fault zone evolution. The location and orientations of linkage structures previously predicted by the simple simulations are consistent with the predicted geometries in the more complex fault zones, however, the exact location at which individual structures form is not easily predicted.

Markedly different fault zone geometries are predicted when the pre-existing joints are rotated with respect to the maximum compressive stress. In particular, fault surfaces range from evolving smooth linear structures to producing complex 'stepped' fault zone geometries. These geometries have a significant effect on simulations of along and across-fault flow.