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Modelling Spatial and Temporal Fault Zone Evolution in Basement Rocks

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There is considerable industrial interest in assessing the permeability of faults for the purpose of oil and gas production, deep well injection of waste liquids, underground storage of natural gas and disposal of radioactive waste. Prior estimation of fault hydraulic properties is highly error prone. Faults zones are formed through a complex interaction of mechanical, hydraulic and chemical processes and their permeability varies considerably over both space and time. Algorithms for predicting fault seal potential using throw and host rock property data exist for clay-rich fault seals but are contentious. In the case of crystalline rocks and sand-sand contacts, no such algorithms exist. In any case, the study of fault growth processes does not suggest that there is a clear or simple relationship between fault throw and the fault zone permeability.

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 through development and application of a 2D hydro-mechanical finite element model. The development of fault zone damage is simulated perpendicular to the main slip surface using a fully coupled solution of Navier's equation for mechanical deformation and Darcy's Law/conservation of fluid mass for subsurface fluid flow. The model is applied to study development of fault zones in basement rocks, based on the conceptual model of S. J. Martell, J. Struct. Geol. 12(7):869-882, 1990. We simulate the evolution of fault zones from pre-existing joints and explore controls on the growth rate and locations of multiple splay fractures which link-up to form complex damage zones. We are the first researchers

to successfully simulate the temporal and spatial evolution of multiple wing cracks, tertiary fracturing, antithetic fractures propagating into the compressive region, infill fracturing between faults and joints, the temporal development of simple fault zones from pre-existing joint patterns, and hydrofracturing during thermal pressurisation. Results from these simulations have been validated using outcrop data and research is now in progress to up-scale our results for determination of statistical parameters describing larger scale spatial permeability structure in faults.