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Fault Damage Zone Permeability in Crystalline Rocks from Combined Field and Laboratory Measurements: Can we Predict Damage Zone Permeability?

T.M. Mitchell (1) and D.R. Faulkner (2)

(1) Hiroshima University, Graduate School of Science, Department of Earth and Planetary Systems Sciences, Hiroshima, Japan (tom-mitchell@hiroshima-u.ac.jp), (2) University of Liverpool, Department of Earth and Ocean Sciences, 4 Brownlow Street, Liverpool, Merseyside, L69 3GP

Models predicting crustal fluid flow are important for a variety of reasons; for example earthquake models invoking fluid triggering, predicting crustal strength modelling flow surrounding deep waste repositories or the recovery of natural resources. Crustal fluid flow is controlled by both the bulk transport properties of rocks as well as heterogeneities such as faults. In nature, permeability is enhanced in the damage zone of faults, where fracturing occurs on a wide range of scales. Here we analyze the contribution of microfracture damage on the permeability of faults that cut through low porosity, crystalline rocks by combining field and laboratory measurements. Microfracture densities surrounding strike-slip faults with well-constrained displacements ranging over 3 orders of magnitude (∼0.12 m – 5000 m) have been analyzed. The faults studied are excellently exposed within the Atacama Fault Zone, where exhumation from 6-10 km has occurred. Microfractures in the form of fluid inclusion planes (FIPs) show a log-linear decrease in fracture density with perpendicular distance from the fault core. Damage zone widths defined by the density of FIPs scale with fault displacement, and an empirical relationship for microfracture density distribution throughout the damage zone with displacement is derived. Damage zone rocks will have experienced differential stresses that were less than, but some proportion of, the failure stress. As such, permeability data from progressively loaded, initially intact laboratory samples, in the pre-failure region provide useful insights into fluid flow properties of various parts of the damage zone. The permeability evolution of initially intact crystalline rocks under increasing differential load leading to macroscopic failure was determined at water pore pressures of 50 MPa and effective pressure of 10 MPa. Permeability is seen to increase by up to, and over, two orders of magnitude prior to macroscopic failure. Further experiments were stopped at various points in the loading history in order to correlate microfracture density within the samples with permeability. By combining empirical relationships determined from both quantitative fieldwork and experiments we present a new model that allows microfracture permeability distribution throughout the damage zone to be determined as function of increasing fault displacement.