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Micromechanics of rock deformation and failure (Louis Néel Medal Lecture)

Teng-fong Wong
Stony Brook University, New York, USA

Naturally deformed rocks and their microstructures provide some of the most useful data for the reconstruction of tectonic evolution. A physically based inference of the operative deformation mechanism and failure mode from such data hinges upon a fundamental understanding of the microstructures induced in samples deformed in the laboratory under controlled conditions. As a field of mechanics that explicitly takes into account the microstructure of a material, micromechanics is linked dynamically to advances in imaging technology, that continues to refine the quantitative characterization of geometric attributes of microstructure and to elucidate the micromechanics of damage evolution. For a porous rock, such imaging techniques together with acoustic emission observations can now provide a fairly comprehensive description of the geometry of the pore space, as well as the density and connectivity of microcracks and equant pores. These microstructural data provide critical constraints on models that strive to capture the micromechanical processes and thus arrive at constitutive relations that describe the inelastic and failure behaviors as observed in the laboratory. Based on concepts of elasticity, plasticity and fracture mechanics, a number of micromechanical models (such as the sliding wing crack, Hertzian fracture, plastic and cataclastic pore collapse) help identify the key microstructural parameters involved and provide important insights into the deformation and failure mechanisms associated with a number of processes related to the development of brittle faulting, shear localization, cataclastic flow and compaction localization. These micromechanical processes typically involve damage evolution that is spatially heterogeneous, the complexity of which can potentially be probed in some details now by numerical simulation. Furthermore, these micromechanical models can provide useful constraints on the evolutions of porosity and permeability, which are often coupled with mechanical deformation and failure in crustal tectonics.