Nucleation and Growth of Microscopic Defects and Disorder in Rock Masses

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Observations of rock masses over a range of spatial scales indicate that the failure modes of these systems, such as fracture, demonstrate scale invariant deformation, or power law behavior, characteristic of complex non-linear systems. These are observed in both laboratory settings in acoustic emission experiments, as well as in large scale field settings associated with tectonic faults (Gutenberg-Richter magnitude-frequency relation; Omori relation for aftershocks). One important reason for this behavior is that driven threshold systems of rock masses in which defects interact with long range interactions display near mean field dynamics and ergodic behavior. This result, which was first proposed on the basis of simulations and theory, was subsequently observed in field observations on the tectonic scale. We are investigating the failure of rock masses resulting from the complex physics of microscopic dynamical processes in rocks, as manifested in the nucleation and growth of defects, microcracks, damage, and macroscopic fracture. These processes are a result of the complex emergent dynamics of self-organizing geological materials which we analyze using the methods of statistical physics and large scale simulations employing both molecular dynamics and Monte Carlo methods. Fully interacting fields of defects and damage are generally not included in most current models for material deformation. Instead, defect density and damage fields are assumed to be non-interacting or dilute, implying a strictly mean field approach. We use statistical physics methods to understand the dynamics of interacting defect and damage fields, made possible by the construction and use of statistical field theories, to greatly improve our predictive capability for the macroscopic failure of materials. In this talk I will summarize our current understanding of rock deformation as a response to stresses driving the evolution of damage and defects within the rock mass. The important quantities to compute are the nucleation rate, or its inverse, lifetime to failure. I will also discuss applications of this research to rock deformation across a range of spatial and temporal scales.