Modeling and Characterization of Fracture and Fluid Flow in Porous Media

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This dissertation presents a comprehensive study of fracture networks in porous media and the polygonal patterns they form in various natural systems. Our approach utilizes a combination of mathematical modeling, simulation, and empirical analysis. A novel four-parameter map is introduced to characterize planar surface fracture networks, summarizing their topological and geometrical properties. This map classifies different materials by grouping them according to similar characteristics of their crack patterns. Columnar joint systems, crack networks in drying colloidal materials, and salt ridge mosaics are also explored on the basis of evolving crack patterns mapped as trajectories in a geometry-topology domain. The dissertation proposes empirical relations between system energy and geometric parameters, demonstrating that many natural systems evolve toward energy minimization, often forming Voronoi-like structures. For 3-dimensional disordered porous materials, crack statistics and the dependence of micro-cracking behavior on elastic properties are analyzed. The analysis reveals two distinct cracking regimes and a power-law relation between critical strains. Additionally, the permeability of porous systems is shown to follow unique scaling relations with the Minkowski functionals, regardless of whether the system is ordered or disordered. These findings provide a deeper understanding of crack mechanics and material behavior across diverse natural systems.

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