The displacement of one fluid by another in a porous medium give rise to a rich variety of hydrodynamic instabilities. Unstable porous-media flows are essential to understanding many processes, including water infiltration in the vadose zone, carbon dioxide injection and storage in deep saline aquifers, and hydrocarbon recovery. We will review the pattern-selection mechanisms of a wide spectrum of porous-media flows that develop hydrodynamic instabilities, discuss their origin and the mathematical models that have been used to describe them. We point out many challenges that remain to be resolved in the context of multiphase flows, and suggest modeling approaches that may offer new quantitative understanding.

In particular, I will present experimental, theoretical and computational results for: (1) fluid mixing from viscous fingering; (2) the impact of wettability on viscously unstable multiphase flow in porous media; (3) capillary fracturing in granular media; and (4) rock dissolution during convective mixing in porous media.

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