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Modelling focused fluid flow: What matters?

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Two-phase flow equations that couple solid deformation and fluid migration have opened new research trends in geodynamical simulations and modelling of subsurface engineering operations. The physical nonlinearity of fluid-rock systems and strong coupling between flow and deformation in such equations lead to interesting predictions such as the spontaneous formation of focused fluid flow in ductile/plastic rocks. However, numerical implementation of two-phase flow equations and their application to realistic geological environments with complex geometries and multiple stratigraphic layers is challenging. Here, we present an efficient pseudo-transient solver for two-phase flow equations. We first study the focused fluid flow under the viscous regime without considering the elasticity. The roles of material parameters, reservoir topology, geological heterogeneity, and porosity are investigated. We show that focused fluid channels are the natural outcome of the flow instability of the two-phase system with a low ratio (< 0.1) between shear viscosity and bulk viscosity. We also confirm the previous studies that decompaction weakening is necessary to elongate the porosity profile. The permeability exponents play the dominant role in the speed of wave propagation. The numerical models study fluid leakage from high porosity reservoirs into less porous overlying rocks. Geological layers present in the overburden do not stop the propagation of the localized channels but rather modify their width, permeability, and growth speed. We further validate our conclusions by modelling the full two-phase system with viscoelastic rheology and elastic solid and fluid compressibility (Yarushina et al., 2015). The Deborah number (De), solid (K_s), and fluid (K_f) bulk moduli are thus introduced into the governing equations. We found that the elasticity makes a difference when the Deborah number approaches one by speeding up the channel propagation. At the same time, its effect is rather limited when Deborah's number is small (e.g., 0.1). The effects of compressibility of the solid and fluid, on the other hand, are not found significant within the reasonable ranges of the bulk moduli.