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Modeling of Multi-Scale Channeling Phenomena in Porous Flow

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Predictive modeling of fluid percolation through tight porous rocks is critical to evaluate environmental risks associated with waste storage and reservoir operations. To understand the evolution of two-phase mixtures of fluid and solid it is insufficient to only combine single-phase fluid flow methods and solid mechanics. A proper coupling of these two different multi-scales physical processes is required to describe the complex evolution of permeability and porosity in space and in time.

We conduct numerical modeling experiments in geometrically simple but physically complex systems of stressed rocks containing self-focusing porous flow. Our model is physically and thermodynamically consistent and describes the formation and evolution of fluid pathways. The model consists of a system of coupled equations describing poro-elasto-viscous deformation and flow. Nonlinearity of the solid rheology is also taken into account. We have developed a numerical application based on an iterative finite difference scheme that runs on mutli-GPUs cluster in parallel.

In order to validate these models, we consider the largest CO_2 sequestration project in operation at the Sleipner field in the Norwegian North Sea. Attempts to match the observations at Sleipner using conventional reservoir simulations fail to capture first order observations, such as the seemingly effortless vertical flow of CO_2 through low permeability shale layers and the formation of focused flow channels or chimneys.

Conducted high-resolution three-dimensional numerical simulations predict the formation of dynamically evolving high porosity and permeability pathways as a natural outcome of porous flow nonlinearly coupled with rock deformation, which may trigger leakage through low permeability barriers.