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Resolving hydro-mechanical coupling in two and three dimensions

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Evidences of localised flow patterns are ubiquitous on Earth and drive a range of geo-processes across all scales. Classical Dacian models predict a diffusive behaviour leading to spreading and delocalisation, observations rather suggest focusing of porous fluids within fingers, veins or channels.

We aim to investigate numerically a physical mechanism, the de-compaction weakening, which leads to the formation and propagation of localised flow pathways in fluid saturated porous media. We use high-resolution two- and three-dimensional numerical modelling to solve nonlinear Darcian porous flow in a viscously deforming matrix using a nonlinear Stokes flow. In order to accurately capture strong localisation in space and time, we streamline matrix-free Pseudo-Transient approaches on graphical processing units. The Pseudo-Transient routines converge towards identical solutions compared to Direct-Iterative solving strategies.

We discuss performance benefits of the matrix-free method on modern parallel hardware. We show that high porosity channels may be a dynamic and natural outcome of sufficiently resolved hydro-mechanical coupling and de-compaction weakening. In addition, we systematically study the channel propagation velocity as a function of bulk and shear viscosity ratios.

We conclude on the viability of buoyancy driven fluid migration at rates up to the three orders of magnitude higher than expected by pure Darcian flow regimes. We provide both the two-dimensional MATLAB based Direct-Iterative and Pseudo-Transient routines for full reproducibility and suggest our model setup as a key benchmark case to validate implementation of hydro-mechanical coupling in two- and three-dimensional numerical codes.