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Use of GPU Computing to Study Coupled Deformation and Fluid Flow in Porous Rocks

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Actual challenges in computational geodynamics put high requirements for the development of new coupled models. These need to solve accurate physics, on high resolution and in reasonable computation time. Multi-scale problems such as deformation of porous rocks triggered by fluid flow require both high temporal and spatial resolution. The resulting preferential flow paths involve complex physics and a strong coupling between deformation and fluid flow processes. Shortcuts such as sequential or iterative coupling of two existing solvers will not be sufficient in these difficult cases to localize the deformation and flow.

We base our numerical implementation on the physically and thermodynamically consistent mathematical model for fluid flow in porous rocks, taking nonlinear stress dependent visco-elasto-plastic rheology into account. The effective permeability used for the Darcy flow is obtained through the nonlinear Karman-Cozeny relation. The model is not restricted by the lithostatic stress assumption, allowing for background stress regime as it occurs in natural conditions.

We have developed a fully three-dimensional numerical application based on an iterative finite difference scheme. The application is written in C-CUDA, is enabled for GPU accelerators and is parallelized with MPI to run on multi-GPU clusters. The parallelization on a rectangular grid is straightforward (at each iteration, the boundaries of the local problem are updated by the neighboring processes) and requires no MPI global operations, only MPI point-to-point communication between neighboring processes. This parallelization method should allow by construction for linear weak scaling on any number of processors.

Our linearly scaling numerical application predicts the formation of dynamically evolving fluid pathways. These supercomuting applications are vital for resolving actual challenging high-resolution three-dimensional models.