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Coupled distinct element-finite element numerical modelling of fluid circulation in deforming sedimentary basins.

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We develop a coupled numerical model for fluid flow in deforming sedimentary basins. We combine a distinct element method for large deformations of crustal materials, with a finite element method for fluid flow according to a diffusion type equation.

The key question in such a model is how to simulate evolving permeabilities due to upper and possibly middle crustal deformation, and the coupled issue of how localisation of deformation in faults and shear zones is itself influenced by fluid flow and fluid pressure and vice versa. Currently our knowledge of these issues is restricted, even sketchy. There are a number of hypotheses, based partly on geological and isotope geochemical observations, such as "seismic pumping" models, and fluid induced weak décollement models for thrust sheet transport which have gained quite wide acceptance. Observations around thrusts at the present day have also often been interpreted as showing deformation induced permeability. However, combining all the physics of these processes into a numerical simulation is a complicated task given the ranges of, in particular time scales of the processes we infer to be operating based on our various observations.

We start this task by using an elastic fracture relationship between normal stresses across distinct element contacts (which we consider to be the equivalent of discrete, sliding fractures) and their openness and hence their transmissivity. This relates the mechanical state of the distinct element system to a discrete permeability field. Further than that, the geometry of the mechanical system is used to provide boundary conditions for fluid flow in a diffusion equation which also incorporates the permeability field. The next question we address is how to achieve a feedback between fluid pressures and deformation. We try two approaches: one treats pore space in the DEM as real, and calculates the force exerted locally by fluids and adds this to the force balance of the model; another considers the DEM to be effectively a continuum, and modifies the contact normal stresses in proportion to local fluid pressures. The former is quite close to a poro-elastic formulation.

We then apply the model to different geological cases. One is a submarine accretionary prism, for which we use the Sunda margin accretionary system as an analogue, with a $\sim$50Ma deformation history and wedge thicknesses of up to 15km in the trench region. We compare our results to reprocessed, depth migrated seismic lines. The other is the Thuringian basin, with its $\sim$200Ma history of intracontinental, mostly subaerial and polyphase deformation. In this case, we deal with a relatively confined basin which is strongly anisotropic. Its height dimension is of the order of 2km, whilst its length dimensions are $\sim$100's kms. In this case we can compare our results to detailed stratigraphic and structural models based on a mixture of well and seismic data and kinematic, structural balancing.