RÄSS Ludovic (2018) : Resolving thermo-hydro-mechanical coupling. Spontaneous porous fluid and strain localization.

Abstract

Localisation of deformation and flow is ubiquitously observed on Earth, spanning from subterraneous locations both in the deep interior and towards the shallow surface. Ductile strain localisation in tectonic processes or channelling and focusing of fluids in porous rocks are widely reported expressions of strain and flow localisation, governed by hydraulic, thermal and mechanical interactions. The intrinsic coupling of these different physical processes provides additional localisation mechanisms to well-established single-process physics. Models that address interactions between different physical processes must include non-linear feedbacks that may potentially trigger new and non-intuitive characteristic length and time scales. Accurately resolving this complex non-linear interplay resulting from coupled physics permits us to better understand the nature of multiphysics processes and to provide more accurate predictions on how, when and where to expect localisation. In many anthropogenic activities related to achieving a carbon-free energy transition, accurate predictions of mid-term to long-term behaviour for geosystems are vital. Engineered waste disposal solutions such as CO2 sequestration and nuclear waste deposits require coupled models in order to predict the complexities of the evolving system. However, there is a current lack in model capability to address the non-linear interactions resulting from multiphysics coupling. Available models of- ten fail to reproduce major first-order field observations of localisation, mainly owing to poor coupling strategies and a lack of affordable resolution needed to resolve very local non-linear features, especially in three spatial dimensions. In this thesis, I address these issues using a supercomputing approach to resolve sufficiently high-resolution stain and flow localisation in non-linearly deforming porous media, relying on a thermodynamically consistent model formulation. The developed graphical processing unit-based parallel algorithms show close to linear weak scaling on the world's third-largest supercomputer and are benchmarked against classical direct-iterative type solvers. The high-resolution computations are needed for the convergence of the calculations. The results confirm that a strong coupling between solid deformation, fluid flow and heat diffusion provides a viable mechanism for 'chimney' formation or strain localisation. Flow localisation in high-permeability chimneys provides efficient pathways for fast vertical fluid migration. By using model parameters relevant for sedimentary rocks, natural observations and their main characteristic features could be reproduced. In summary, this thesis provides an extensive study on hydro-mechanical interaction in fluid- saturated and non-linearly deforming porous rocks. Further, the predicted high-permeability pathways are vital to understand the formation of potential leakage pathways and are a prerequisite for reliable risk assessment in long-term waste storage. Finally, the developed solution strategy is successfully utilised to resolve strain localisation in thermo-mechanically coupled processes.