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How porosity and damage evolutions influence the deformation modes within the lithosphere

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Two main deformation modes are thought to control the long-term strength of the lithosphere: frictional – pressure-dependent – brittle deformation, and Arrhenius-type thermally activated creep. Dynamic changes in terms of forcing conditions (from natural, tectonic driven to anthropogenic ones) can also exert changes in the strength profile. The shape of a strength- profile determines at which depth differential stresses could be accumulated and therefore impose self-consistent bounds to the amount of energy which could be released in a seismic or aseismic way. The brittle-ductile transition is a domain of finite extent where high differential stress can accumulate and where both (semi)-brittle and (semi)-ductile deformation mechanisms are expected to occur. The depth of this region highly depends on two parameters: the thermal state of the system as the main controlling factor activating creep mechanisms and therefore lowering the rock strength and the friction coefficient controlling the pressure-dependent brittle regime.

Understanding the location at depth of the brittle-ductile transition and its stability though time has become of relevance for targeting high-enthalpy unconventional geothermal resources as found in volcanic settings, where the thermal conditions may activate ductile deformation at shallower depths than expected. Extracting heat from such systems requires to quantify the evolution of porosity and permeability and their distribution at depth. Laboratory experiments on porous rocks clarified how porosity evolution in time and space exerts a critical control on the different deformation modes (from diffused to localised), dynamically buffering the transition from one mode to the other which might induce changes in permeability up to several orders of magnitudes. However, few numerical models have succeeded to account for such porosity feedbacks on the deformation of porous rocks.

We make use of the numerical simulator LYNX (Lithosphere dYnamic Numerical toolboX), which relies on an implicit multiphysics coupling of the physics describing the deformation modes as they occur in the rigid portion of the lithosphere including thermal, mechanical and hydraulic feedbacks. In particular, we include effects that control the microstructure evolution and its feedbacks on the macroscopic deformation, formulated in terms of damage and porosity evolution.

In this contribution, we present a thermodynamically-consistent physical framework to describe the physical processes controlling deformation dynamics in the vicinity of the brittle-ductile transition. We will focus in particular on (i) the role of damage weakening and its impact on the evolution of localised deformation and (ii) the role of porosity evolution as a driving mechanism and indicator of deformation modes. These two aspects allow us to gain insights into the influence of localised deformation onto the strength of lithospheric rocks and on their hydraulic behaviours. We will present numerical examples describing the dynamics of these two aspects ranging from laboratory to lithosphere scales.