Thermodynamic consistent formulation for the multiphysics of a brittle ductile lithosphere - semi-brittle semi-ductile deformation and damage rheology

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We provide details on a novel formulation derived to describe the multiphysics controlling the deformation of porous rock under lithospheric conditions. The theory is developed consistent with the principles of thermodynamics and enables to capture the behaviour of porous rocks at the transition from frictional brittle behaviour to ductile viscous behaviour. It also accounts for the nonlinear feedback mechanisms derived from energetic consideration for the bi-phasic fluid-rock matrix system.

The formulation depicts a consistent, implicit visco-elasto-(visco)plastic rheology accounting for both a volumetric and a deviatoric response to applied loads, thereby avoiding the use of, the commonly assumed, plasticity limiter concept. The overstress plastic formulation introduces rate dependent mechanical behavior, an aspect that is consistent with experimental rock mechanics evidence and is also demonstrated to improve numerical stability when addressing problems related to plastic strain accumulation even in the absence of energetic feedbacks.

The introduction of a damage rheology permits to account for microstructural processes responsible for brittle-like material weakening and rate-dependent dissipative material behavior. The presence of a fluid phase is considered via a dynamic porosity, the evolution of which is demonstrated to primarily control the volumetric mechanical response of the stressed rock during incremental loading.

The above formulation has been integrated in a massively parallel, open source numerical framework with interfaces to state of the art HPC clusters. The results of a scalability and profile performance analysis on multi-core supercomputer are presented alongside with dedicated applications describing lithospheric rock deformation under different confining conditions as well as the bulk macroscopic material response recorded by laboratory experiments under triaxial conditions.

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