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Towards coupling fluid flow and rate-and-state friction in compacting visco-poro-elasto-plastic reservoirs

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Induced seismicity as a result of natural gas production is a major challenge from both an industrial and a societal perspective. The compaction caused by gas production leads to changes of the effective pressure fields in the reservoir and stress redistributions occur particularly in the surrounding faults. In addition, the strong coupling between fluid flow and solid rock deformations and the role of fluid flow regarding the frictional properties of the faults necessitate a coupled and comprehensive modeling framework. A general and fully coupled thermo-hydro-mechanical finite difference formulation is developed herein and the results are verified against numerical benchmarks. A visco-elasto-plastic rheological behavior is assumed for the bulk material and a return-mapping algorithm is implemented for accurate simulation of the stress evolution. The geometrical features of the faults are incorporated into a regularized continuum framework, while the response of the fault zone is governed by a rate-and-state-dependent friction model. Numerical simulations are provided for large-scale problems and their efficiency is assured through the evaluation of the consistently linearized systems of equations along with the use of advanced numerical solvers and parallel computing. Although the proposed framework is a step towards the modeling of earthquake sequences for induced seismicity applications, the features of the numerical model are highlighted for other applications, including seismic events in subduction settings where the role of fluid flow inside the faults is considerable. Another application of the present, fully coupled hydro-thermo-mechanical formulation is the prediction of the fluid pressurization phenomena, where the frictional heating increases the magnitude of the pore fluid pressure inside the faults, and the resultant degradation of dynamic frictional strength is naturally captured.