GC11-solidearth-32, updated on 13 May 2024
https://doi.org/10.5194/egusphere-gc11-solidearth-32
Galileo Conference: Solid Earth and Geohazards in the Exascale Era


# Numerical simulation of injection-induced seismicity

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Geo-energies, such as geothermal energy, geologic carbon storage, and subsurface energy storage, will play a relevant role in reaching carbon neutrality and allowing net-carbon removal towards the midcentury. Geo-energies imply fluid injection into and/or production from the subsurface, which alter the initial effective stress state and may destabilize fractures and faults, thereby inducing seismicity. Understanding the processes that control induced seismicity is paramount to develop reliable forecasting tools to manage induced earthquakes and keep them below undesired levels. Accurately modeling the processes that occur during fracture/fault slip leading to induced seismicity is challenging because coupled thermo-hydro-mechanical-chemical (THMC) processes interact with each other: (1) fluid injection causes pore pressure buildup that changes total stress and deforms the rock, (2) deformation leads to permeability changes that affect pore pressure diffusion, (3) fluids reach the injection formation at a colder temperature than that of the rock, which cools down the vicinity of the well, causing changes in the fluid properties (density, viscosity, enthalpy, heat capacity) and cooling-induced stress reduction, (4) the injected fluids are not in chemical equilibrium with the host rock, leading to geochemical reactions of mineral dissolution/precipitation that may alter rock properties, in particular, the shear strength. In the framework of GEoREST (www.georest.eu), a Starting Grant from the European Research Council (ERC), we aim at developing forecasting tools for injection-induced seismicity by developing methodologies to efficiently simulate the coupled THMC processes that occur as a result of fluid injection, which allows us to improve the understanding of the mechanisms that trigger induced seismicity. To this end, we use the fully coupled finite element method software CODE_BRIGHT, which includes capabilities like friction following the Mohr-Coulomb failure criterion with strain weakening and dilatancy, enabling simulations of fracture/fault reactivation. Our investigations have already contributed to the understanding of the processes that induced the seismicity at the Enhanced Geothermal System (EGS) at Basel, Switzerland, at the Castor Underground Gas Storage, Spain, and the reservoir-induced seismicity at Nova Ponte, Brazil. To achieve scalability and speed up the calculations to eventually manage induced seismicity in real time, we intend to incorporate efficient state-of-the-art linear solvers, like HYPRE and PETSc, in CODE_BRIGHT.