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Interaction of processes may explain induced seismicity after shut-in in Enhanced Geothermal Systems

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Deep fluid injection is a necessary operation in several engineering sectors, like geothermal energy production, natural gas storage, CO_2 storage, etc. The seismicity associated to these activities has, in some occasions, reached unexpected magnitude, raising public concern. Moreover, the occurrence of such seismicity after the injection shut-in pointed out the incompleteness of the knowledge and the inability of fully managing these processes. On the other hand, the growing attention toward clean energy makes it clear that we cannot abandon these procedures, which have a huge potential. Therefore, deeply understanding the mechanisms that induce seismicity is crucial.
In this study we consider hydraulic stimulation of deep geothermal systems and analyze the mechanisms that may induce or trigger seismicity. Given that the basic mechanism is fluid pressure increase, secondary triggering processes have been studied. In detail, we attempt to identify the potential mechanisms that may trigger seismicity in the post-injection phase, when the overpressure decreases. These mechanisms have been investigated with a coupled and uncoupled approach, in order to understand the individual effects of each one and the effects of the interactions between them on the reservoir stability.
Besides fluid overpressure, another relevant process is the temperature variation. Indeed, in the case of enhanced geothermal systems, the temperature contrast between the injected cold fluid and the deep hot reservoir is great and induces thermal stress, which sensibly affects the in-situ stress field. Therefore, we have studied overpressure and temperature effects by means of analytic solutions and by means of hydro-mechanical and thermo-hydro-mechanical numerical simulations. Results show that in fractured rocks the spatial variability of hydraulic and mechanic parameters provokes no isotropic variation of the tensional field, in response to pressure and temperature perturbations.
Another potential mechanism is due to the slip stress transfer. Once failure conditions are reached along a fault or fracture, shear slip is activated and seismic waves propagate. It is well-known that this slip movement affects the stress field in the neighborhood of the slipped fault or fracture. We analyzed the rotation of the stress tensor due to the slip stress transfer and applied it to the thermo-hydro-mechanic simulation results. Results show that the interaction of these different processes may explain post-injection seismicity on not favorably oriented faults.