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Comparative modeling of fault reactivation and seismicity in geologic carbon storage and shale-gas reservoir stimulation

Jonny Rutqvist, Antonio Rinaldi, and Frederic Cappa
(jrutqvist@lbl.gov)

The potential for fault reactivation and induced seismicity are issues of concern related to both geologic CO_2 sequestration and stimulation of shale-gas reservoirs. It is well known that underground injection may cause induced seismicity depending on site-specific conditions, such a stress and rock properties and injection parameters. To date no sizeable seismic event that could be felt by the local population has been documented associated with CO_2 sequestration activities. In the case of shale-gas fracturing, only a few cases of felt seismicity have been documented out of hundreds of thousands of hydraulic fracturing stimulation stages. In this paper we summarize and review numerical simulations of injection-induced fault reactivation and induced seismicity associated with both underground CO_2 injection and hydraulic fracturing of shale-gas reservoirs. The simulations were conducted with TOUGH-FLAC, a simulator for coupled multiphase flow and geomechanical modeling. In this case we employed both 2D and 3D models with an explicit representation of a fault. A strain softening Mohr-Coulomb model was used to model a slip-weakening fault slip behavior, enabling modeling of sudden slip that was interpreted as a seismic event, with a moment magnitude evaluated using formulas from seismology. In the case of CO_2 sequestration, injection rates corresponding to expected industrial scale CO_2 storage operations were used, raising the reservoir pressure until the fault was reactivated. For the assumed model settings, it took a few months of continuous injection to increase the reservoir pressure sufficiently to cause the fault to reactivate. In the case of shale-gas fracturing we considered that the injection fluid during one typical 3-hour fracturing stage was channelized into a fault along with the hydraulic fracturing process. Overall, the analysis shows that while the CO_2 geologic sequestration in deep sedimentary formations are capable of producing notable events (e.g. magnitude 3 or 4); the likelihood for such felt events is much smaller in the case of shale-gas fracturing. The reason is that CO_2 geological sequestration involves injection and pressure disturbances at much larger scale and with much larger reservoir permeability than in the case of shale gas fracturing. In the case of shale-gas fracturing, the expected low permeability of faults intersecting gas saturated shales is clearly a limiting factor for the possible rupture length and seismic magnitude. For a fault that is initially impermeable, the only possibility of larger fault slip events would be opening by hydraulic fracturing allowing pressure to permeate along the fault causing a reduction in the frictional strength over a sufficiently large fault surface patch and very brittle fault properties that would allow shear slip to develop over a sufficient large rupture area.