Aseismic motions drive a sparse seismicity during fluid injections into a fractured zone in a carbonate reservoir

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An increase in fluid pressure in faults can trigger seismicity and large aseismic motions. Understanding how fluid and faults interact is an essential goal for seismic hazard and reservoir monitoring, but this key relation remains unclear. We developed an in-situ experiment of fluid injections at a 10-meter scale. Water was injected at high-pressure in different geological structures inside a fault damaged zone, in limestone at 280 m depth in the LSBB Underground Laboratory (France). Induced seismicity, as well as strains, pressure and flowrate were continuously monitored during the injections. Although plastic deformations related to fracture reactivations were observed for all injections, only a few tests generated seismicity. Events are characterized by a 0.5-to-4 KHz content and a small magnitude (approximately -3.5). They are located within 1.5 m accuracy between 1 and 12 m from the injections. Comparing strain measurements and seismicity shows that more than 96% of the deformation is aseismic. The seismic moment is also small compared to the one expected from the injected volume. Moreover, a dual seismic behavior is observed as (1) the spatio-temporal distribution of some cluster of events is clearly independent from the fluid diffusion (2) while a diffusion-type pattern can be observed for some others clusters. The seismicity might therefore appear as an indirect effect to the fluid pressure, driven by aseismic motion and related stress perturbation through failure [2]. Using hydromechanical modeling with friction laws, we simulated an experiment and investigated the relative contribution of the fluid pressure diffusion and stress transfer on the seismic and aseismic fault behavior. The model reproduces the hydromechanical data measured at injection, and show that the aseismic slip induced by fluid injection propagates outside the pressurized zone where accumulated shear stress develops, and potentially triggers seismicity. Our models also show that the permeability enhancement and friction evolution are essential to explain the fault slip behavior. Our experimental results are consistent with large-scale observations of fault motions at geothermal sites [1,3], and suggest that controlled field experiments at meter-scale are important for better assessing the role of fluid pressure in natural and human-induced earthquakes.

Key words: fluid injection, fault zone, hydromechanics, induced seismicity, aseismic motions, in-situ experiments.

References

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