Fault reactivation process in the laboratory: The role of stress cycling and pressurization rate

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Over the last few decades, it has become apparent that different human activities in the subsurface, such as water waste injection, hydraulic fracturing, and geothermal energy production can lead to induced seismicity. Understanding the effects of fluid injection-related parameters on seismic response or evolution of it is essential for finding a method to manage and minimize the induced seismicity risk. Experimental and numerical studies indicate that varying injection patterns and rates can be used to effect and/or mitigate seismicity. However, most of the studies are for intact rock medium, and the mechanism of injection-induced seismicity of faulted rock medium is not clear yet. In this study, we performed fault reactivation experiments on faulted (saw-cut) Red Pfaelzer sandstones to provide new insight into the effect of stress/pressure cycling and rate on fault slip behavior and seismicity evolution. The saw-cut samples were subjected to two different reactivation mechanisms: 1) stress-driven and 2) injection-driven fault reactivation. Three different reactivation scenarios were performed during the stress-driven fault reactivation experiments: continuous sliding, cyclic sliding, and under-threshold cycling sliding. Ten AE transducers were used to detect microseismicity during the fault reactivation experiments, and consequently, different microseismic parameters, such as frequency-magnitude distribution (b-value), AE energy, and AE rate were estimated. Stress-driven fault reactivation experiments showed that (i) a below-threshold cycling scenario prevents seismicity and pure shear slip; however if the shear stress exceeds the previous maximum shear stress, seismicity risk increases drastically in terms of b-value, maximum AE energy, and magnitude. (ii) Compared to continuous sliding, cyclic sliding triggers less seismicity in terms of total b-value and large AE events due to the uniform reduction in roughness and asperity on the fault plane. (iii) By increasing the number of cycles, in general, the number of generated events and AE energy per cycle is reduced. Nevertheless, there is a risk of generating large AE events during the first cycles. In addition, results from the injection-driven fault reactivation experiments demonstrated that high injection rate results in higher peak slip velocity. Compared to the stepwise injection pattern, the cyclic recursive injection scenario showed higher peak slip velocity, due to the high hydraulic energy budget and fault compaction. A proper injection strategy needs to consider various factors, such as fault drainage, critical shear stress, injection rate, and injection pattern (frequency and amplitude). Our results demonstrate that selecting proper stress/pressure amplitude, and pressurization rate for the injection design strategy can help to reduce seismicity risk.