EGU21-13656, updated on 01 Dec 2021
https://doi.org/10.5194/egusphere-egu21-13656
EGU General Assembly 2021

Laboratory study on seismicity mitigation: The role of loading pattern and rate

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Reactivation of pre-existing faults/fractures in the reservoir due to the deep injection is a key concern in designing and running geothermal and water/CO_2 injection projects. Therefore, we investigate potential methods to manage injection-induced seismicity. Recent laboratory and field studies recommend that changes in injection pattern (e.g., cyclic injection) might trigger less seismicity than monotonic injection. This study presents results from uniaxial compressive laboratory experiments performed on high porosity Red Felser sandstone that provide new information about the effect of loading pattern and rate on injection driven seismicity. Red Felser sandstone samples with identical porosity and dimensions were subjected to three different loading patterns, including cyclic recursive (CR), cyclic progressive (CP), and monotonic loading. Besides, three different loading rates (displacement control) were applied for each loading pattern: low, medium, and high rates that are 10^{-4} mm/s, 5×10^{-4} mm/s, and 5×10^{-3} mm/s, respectively. Microseismicity analysis shows that (i) the maximum magnitude of seismic events and seismic radiated energy at failure decrease for lower loading rates and during the cyclic loading scenario, (ii) the b-value (magnitude-frequency distribution of events) increases on average 40% for a low-rate cyclic recursive loading in comparison with high-rate cyclic recursive and monotonic loading at different rates. The largest b-value resulted from a low-rate cyclic recursive (LCR) loading pattern. The b-value was estimated and compared using different methods, including a least-square regression on either an incremental frequency distribution or a cumulative frequency distribution, and with the maximum likelihood method (MLM) to provide a reliable b-value estimation. The analyses indicate that by considering the accurate magnitude of completeness, MLM, and, with a least-square regression, the incremental frequency distribution, both result in a reliable b-value. From a mechanical perspective, a low loading rate reduces the sample's final strength by 19%. Moreover, samples subjected to cyclic loading display more complex fracture patterns and more disintegration. In our laboratory study, a combination of low-rate loading and a recursive cyclic loading pattern resulted in reduced seismicity through decreasing the maximum seismicity magnitude and increasing the b-value.