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PSP12

Seismic Efficiency, Overshoot and Enhanced Dynamic Weakening of Fractures

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SUMMARY

see attached extended abstract

Microseismic waveforms recorded during reservoir stimulations, either for long-term injection programs (steam or water-flood in reservoirs with similar geology) or short duration hydraulic fracturing contain unique information on the fracturing process, in particular the dynamics of the rupture process itself. By investigating seismic energy (energy budget) and stress release parameters associated with these events we can identify the type of rupture we are seeing, be it a simple or complex rupture, where the complexity is responding, for example, to the failure of patches on the rupture surface, variations in resisting stress during rupture, barriers to rupture, or a self-healing of the surfaces themselves. In this study, to better understand source dynamics we investigate the radiated energy and Savage-Wood Efficiency of datasets of microseismic events recorded in long-term steam and water injection reservoirs, as well as during hydraulic fracture stimulations in unconventional reservoirs. We also consider how a departure from 0.9β rupture velocity (β – shear wave velocity) can affect the interpretations. Our objective is to better understand the failure process of induced microseismic events and understand their rupture behavior. Our results, as shown in figure 1, that events recorded in a reservoir treated by steam injection (4069 events with Mw = -2.5 to -0.3) had low efficiency events (overshoot € < 0.5), whereas events that occurred in a reservoir treated with water injection (1763 events with Mw = -1.36 to 1.78) had 1545 events with low efficiency and 216 events with high efficiency (undershoot € > 0.5). Overshoot, a measure of how large the dynamic strength is relative to the residual stress (normalized by the static stress drop) predominates in both reservoirs. Observed lower overshoot values were indicative of lower efficiency events and conversely higher observed overshoot values were suggestive of high efficiency and enhanced dynamic weakening. It is clear that the larger range in magnitudes correlates to a larger range in seismic efficiencies and inferred varying source dynamics. In our hydraulic fracture stimulation example, we show how all events are dominated by overshoot behavior. Interestingly, the rupture velocities are considerably slower than theoretically predicted, ranging from 0.4β to 0.6β. Additionally, rupture velocities apparently increase with magnitude, as do the values of dynamic stress drop, suggesting that the ruptures are simpler with increasing magnitude. Based on our analyses, we suggest that the inference of underlying variability in the source behavior (dynamics) provides an opportunity to further investigate the effectiveness of injection programs.

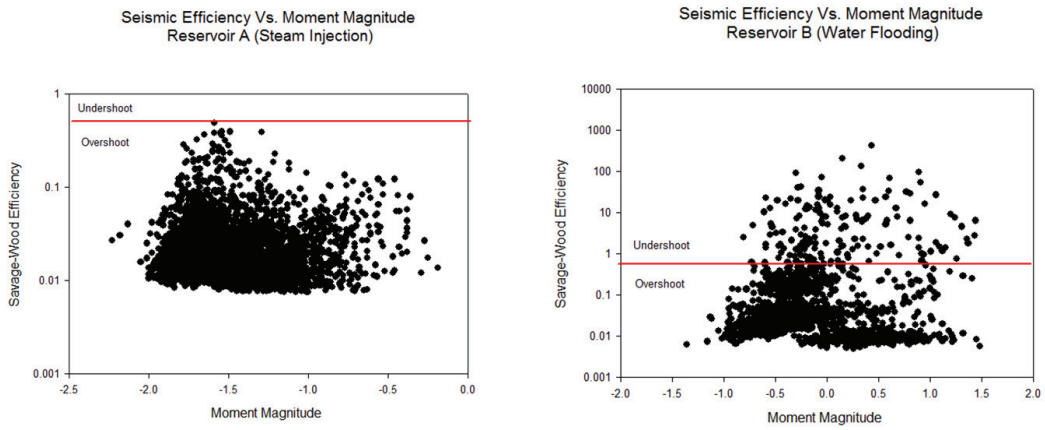

Figure 1 *Savage-wood efficiency for seismicity in two reservoirs responding to steam injection (left) and water flooding (right).*