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Source Characteristics and Failure Process of Hydraulic Fracturing Micro-Seismic Events Located Within and Below the Target Formation

Gisela Viegas[1] and Ted Urbancic[1]

[1]ESG Canada Inc., Kingston, ON, Canada

Abstract

We investigate and compare the source characteristics and failure process of two clusters of micro-seismic events induced during a hydraulic fracturing shale completion program: one composed of small magnitude (<-M1) events located within the target formation, typical of hydraulic fracturing treatments, another composed of larger magnitude (>M0) events located below the treatment zone, associated with slip on pre-existing faults. The difference in the failure process of the two clusters, conditioned by fracture strength, local stress and its perturbation mechanism, is reflected in the source signal. The micro-seismic events are well recorded by a hybrid system consisting of large-aperture multi-well-arrays of high-frequency geophones deployed near the source, and arrays of accelerometers and low-frequency geophones deployed near the surface, which captures a larger bandwidth than typical downhole recording systems, thereby allowing for the analysis of the rupture process at various scales. We calculate static and dynamic source parameters, such as stress drops, radiated energy, and seismic efficiency using various time and frequency analysis methods. The clusters follow different scaling relationships with deep events having higher average stress drops. We calculate full moment tensor solutions and determine fracture planes using stress field information. Relative to the regional maximum horizontal stress, deep events have fracture planes orientated close to the optimal failure direction, and in zone events show mostly perpendicular oriented fractures, consistent with tensile mechanisms. We investigate the differences in the two rock weakening processes to injection. We calculate rupture velocities and analyze the energy budget and rupture complexity as it provides constraints on the initiation and healing of the rupture mechanism, where high frequencies relate to fault edge effects and breaking of asperities and low frequencies with the overall slip on the fault.