Hydraulic fracturing induced hybrid earthquakes in the Montney Basin, British Columbia, Canada may mark the transition from aseismic slip near the wellbore to seismic slip at greater distances

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Seismicity related to fluid injection during unconventional oil and gas exploration has increased dramatically in North America in the last decade. The Western Canadian Sedimentary Basin experienced a significant increase in the number of M3+ earthquakes, including several M4+ associated with high-pressure stimulation during Hydraulic Fracturing (HF) activity. The vigorous seismic response to injection activity and low historical seismicity rates pose critical questions as to the triggering mechanism(s) and seismic hazard assessment in the affected areas. To monitor seismicity linked to injection, a dense local network of eight broadband seismic stations was installed in 2015 at distances of ~2 km around an active well pad with the purpose of monitoring seismicity prior to, and following, a HF well stimulation in the Montney Play in British Columbia, Canada. Here we present an earthquake source process study using observations from the local station network, and provide evidence for a slow-rupture seismic signal which may bridge the spectrum of fault slip rates from aseismic near the well bore, to typical seismic velocities at distances beyond ~1 km.

Initial detection and relocation of seismicity between May 28 – October 15, 2015 yielded 350 well-constrained hypocenters of high-frequency events with a maximum magnitude of $M_w$ 1.8 that resemble typical tectonically generated earthquakes. The detection procedure also yielded a total of 31 events with high-frequency (or broadband) onsets, that transition to protracted, low-frequency ringing relative to event magnitude, which we term hybrids. Both hybrid and high-frequency events occur at similar depths to the active well bore and at distances of ~1-2 km from injection stages, yet exhibit varying source characteristics in spite of their proximal source volumes. Hybrid waveforms are marked by broader P- and S-wave arrival pulse shapes, and spectral fitting suggests that the stress drop values are roughly an order of magnitude lower than high-frequency events, with average static stress drop values of 0.3 MPa and 4.9 MPa, respectively. We interpret wider phase arrival pulse widths and lower stress drop values as resulting from lower rupture velocities of hybrid events relative to high-frequency events. A dilatant strengthening effect would be expected in close proximity to the well bore, and near the hybrid sources, where material is weaker and pore pressures are elevated, which may result in slower rupture...
propagation when slip is initiated relative to further distances where material damage and pore
pressure perturbation are both lower. Thus, hybrid earthquakes may mark regions where slip
velocities transition from aseismic sliding directly next to the well bore, which has been observed
in laboratory and meso-scale experiments, to typical seismic velocities at further distances. The
size-duration scaling of the induced hybrids observed here also extends the scaling of slow
earthquakes occurring in tectonic fault transition zones, and may provide the first observations to
extend the scaling down to seismic moment values of \(~10^{10}\).