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Can progressive injections reduce induced seismicity? - A characterization of acoustic emissions from a hydraulic-fracturing experiment at Äspö Hard Rock Laboratory

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During six in-situ, multi-stage hydraulic fracturing (HF) experiments performed at the Äspö Hard Rock Laboratory (Sweden) at a depth of 410 m hydraulic fracturing growth and induced seismicity were studied under controlled conditions for different fluid-injection schemes. Here we will focus on two schemes: continuous and progressive. The former is a conventional scheme, while the latter is used for fatigue hydraulic fracturing, a method developed to mitigate induced seismicity with potential applications to enhanced geothermal systems. Induced acoustic emissions (AEs) were recorded by a close network of 11 piezoelectric borehole sensors covering a volume of 30x30x30m around a horizontal, 28m long injection borehole. Sensors are most sensitive in the frequency range of 1 to 100 kHz, but sampling rates were extended to 1 MHz.

We set up a semi-automatic work-flow, which is relying on waveform based detection, classification and localization procedures, to extract and characterize high-frequency AEs from continuous recordings. The detection of events is based on a stack-and-delay approach to identify events in the recording and an additional classifier based on Hidden Markov Models to exclude false detections. The detected events are located using an automated full waveform location algorithm based on the stacking of characteristic functions and a coherence analysis. Magnitudes are calculated on a relative scale using maximum amplitudes across the station network.

Through this process, we were able to increase the catalog of AE activity from 196 triggered events to more than 3000 events extracted from the continuous recordings. This allows to study single HF experiments and their rupture processes in greater detail. For the conventional experiments the hypocenters are spatially clustered in planar regions, revealing a main fracture plane, while the progressive injection scheme results in a less constraint cloud-like hypocenter distribution. Despite a similar volume of injected water the maximum magnitude induced by the progressive injection is smaller compared to the conventional scheme. A comparison of the frequency-magnitude distributions indicates that the b-value is larger for the seismicity induced by the progressive injection scheme implying an increased number of small events relative to the large ones.