Source parameter estimation of hydraulically-induced acoustic emissions in the laboratory

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Hydraulic fracturing is used to increase the permeability of tight rock in unconventional reservoirs such as shale gas/oil. Because the influence of the fracturing is often monitored by using microseismic activities, it is important to understand the characteristics of induced seismic events. For this purpose, we conducted hydraulic fracturing experiments in a laboratory. We measured very small seismic events called acoustic emissions (AEs) during the fracturing and estimated their seismic moment, corner frequency, and stress drop.

We used Kurkami-jima granite and Eagle Ford shale blocks with dimensions of 65x65x130 mm. The experiments were conducted under 5 MPa uniaxial load. We drilled a wellbore of 6 mm in diameter in the center of the block and injected fracturing fluid into the wellbore at a rate of 1 cc/min. AE signals were continuously recorded by 24 AE sensors at 10 MHz sampling rate by a 14-bit analog-to-digital converter. From the recorded waveforms, we made AE catalogs by detecting AE events and determining their hypocenters according to the procedure of Naoi et al. (2018; IJRMMS). We also conducted transmission tests immediately before the fracturing experiments under 5 MPa load and estimated sensor coupling conditions and attenuation factor of the specimen from their P-wave first motions and amplitudes. For the AE events occurring in the fracturing, we estimated seismic moment tensors by using the amplitudes and polarities of P-wave first motions after correcting the coupling condition of individual sensors. The obtained moment tensors revealed that the tensile events were dominated for experiments of Eagle ford shale (Imakita et al. 2019 SSJ), and the both of shear and tensile events occurred for Kurokami-jima granite (Yamamoto et al. 2019 GJI; Tanaka et al. 2019 SSJ).

We estimated absolute seismic moments for the obtained AE events by fitting theoretical spectra to observed ones. AE sensors have complex frequency characteristics comparing to seismometers, and, in addition, it depends on the setting method to the specimen. Imakita et al. (2019 SSJ) evaluated the frequency response of the AE sensors under the settings method same as the actual fracturing experiments by using a Laser Doppler velocimeter. We evaluated seismic moment Mo and moment magnitude Mw after correcting the sensor response, and we obtained the estimates -8.5 to -6.0 in Mw. The size distribution of the obtained Mw roughly obeyed the Gutenberg-Richter law, although significant kink was found for the results for granite. This may result from the characteristic scale of grains constituting the granite.

We also estimated corner frequencies by spectral ratio approach (e.g., Ide et al. 2003 JGR) for the obtained AEs. Stress drops of 0.01–1 MPa were calculated for shear events that were observed during the experiments of the granite, under the assumption of a circular crack model. These estimates were 1-order smaller than the typical values of stress drops repeatedly reported for earthquakes (e.g., Yoshimatsu et al. 2014). Such smaller stress drops may result from pressurized fluid (e.g., Chen and Shearer 2011 JGR) or the low-stress condition of only 5 MPa load. We also obtained similar corner frequencies for AEs in Eagle Ford shale, despite the fact that tensile events were dominated for the specimen.

Keywords: Acoustic Emissions, Induced earthquakes, Source parameters, Hydraulic fracturing