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New Insights into Fracture Process through In-Situ Acoustic Emission Monitoring during Fatigue Hydraulic Fracture Experiment in Äspö Hard Rock Laboratory

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Abstract

In this study we analyze the nano- and picoseismicity recorded during the Fatigue Hydraulic Fracturing (FHF) in situ experiment performed in Äspö Hard Rock Laboratory, Sweden. The fracturing experiment composed of six fractures driven by three different water injection schemes (continuous, progressive and pulse pressurization) was performed during the year 2015 inside a 28 m long, horizontal borehole located at 410 m depth. The fracturing process was monitored with two different seismic networks covering a wide frequency band between 0.01 Hz and 100000 Hz, including broadband seismometers, geophones, high frequency accelerometers and acoustic emission sensors. The combined seismic network allowed for detection and detailed analysis of nearly 200 seismic events with moment magnitudes $M_W < -4$ that occurred solely during the hydraulic fracturing stages. We relocated the seismic catalog using double-difference technique and calculated the source parameters (seismic moment, source size, stress drop, focal mechanism and seismic moment tensor). The derived physical characteristics of induced seismicity are compared with the stimulation parameters as well as with the geomechanical parameters of the site.

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Keywords: hydraulic fracturing; acoustic emissions; source parameters; seismic moment tensors

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1. Introduction

The geothermic Fatigue Hydraulic Fracturing (FHF) in situ experiment (Nova project 54-14-1) was performed in the Äspö Hard Rock Laboratory/Sweden situated in granitic to dioritic rocks with an age of about 1.8 Ma [1]. The experiment aimed at optimizing geothermal heat exchange in crystalline rock mass by multistage hydraulic fracturing. At a depth of 410 m, six fracture stages were initiated using three different water injection schemes (continuous, progressive and pulse pressurization) inside a 28 m long, horizontal borehole (Figure 1), with up to 30 dm^3 during each fracture stage.

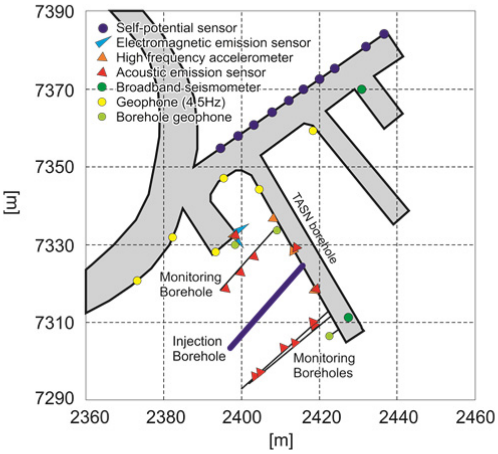

Fig. 1. The map view of all sensors during the hydraulic fracture experiment.

The rock volume surrounding the hydraulic fracturing tests was monitored by three different and independent networks equipped with Acoustic Emission (AE) and accelerometers, short and long-period geophones as well as electromagnetic sensors (Figures 1, 2). The monitored volume was about 30 m x 30 m x 30 m in size. The 16-channel in-situ AE monitoring network manufactured by GMuG [2–5] predominantly used in this study monitored the rupture generation and propagation in the frequency range from 1000 Hz to 100000 Hz using combined 11 acoustic emission sensors and 4 high-frequency accelerometers (1 channel spared for time synchronization between different networks). The acquisition system operated at 1 MHz sampling rate. This monitoring setup was successfully used before [2, 6, 7] to detect and analyze seismic events with rupture dimensions from a few cm- to m-scale [6]. However the environment in Äspö Hard Rock Laboratory was a different one; we had 4-5 Liters/minutes inflow and sensors and equipment had to be adapted to the wet facility. The additional microseismic network covered the lower frequency range from hundreds of hertz to 100 seconds (Figure 2) targeting potentially stronger seismic events. The in-situ AE monitoring system detected and analyzed AE activity in-situ in online mode (P- and S-wave picking, localization). To locate earthquakes, an isotropic velocity model was used. After each stimulation, the results of monitoring were reviewed in order to assess the ongoing microfracturing activity and adjust/improve the monitoring strategy.