Laboratory evidence for Krauklis wave resonance in fractures

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Understanding fluid-saturated reservoir rocks is essential for the applications of, for example, CO_2-sequestration, hydrocarbon exploration, or underground nuclear waste disposal. Seismic waves are influenced by the fluids in reservoir rocks, leading to dispersion and frequency-dependent attenuation (Biot, 1962). A reliable rock characterization can be obtained if the effects of fluids filling the pore and fracture space on the seismic response are well understood.

The Krauklis wave is a unique seismic waveform, which is bound to fluid-filled fractures and propagates along such fractures. It is highly dispersive with low phase velocity at low frequency (Korneev, 2008). It is expected to be able to resonate and emit seismic signals with a signature frequency. This resonant behavior should lead to strong frequency dependence for seismic body waves, enabling the identification of Krauklis wave-related signals in the coda of recorded seismograms (Korneev, 2008). Aki et al. (1977) and Chouet (1996) used this resonance behavior in interpreting volcanic tremor to show the potential of volcanic eruption forecasting. Identifying the characteristics of Krauklis waves in recorded seismograms might be one of the keys to reveal fracture-related petrophysical parameters of reservoirs.

Several theoretical studies have demonstrated analytically the dispersion behavior of Krauklis waves in infinitely long and straight fractures (e.g., Korneev, 2008). However, purely analytical methods cannot reveal the realistic fracture geometries or finite-length fractures. Therefore, we combine numerical modeling results with laboratory experiments to study and visualize fracture-related effects on seismic wave propagation in reservoir rocks. Frehner (2014) demonstrated that the initiation of Krauklis waves depends significantly on fracture orientation and on the incident wave mode. Moreover, Krauklis waves generated by an incident S-wave might carry more information about the fracture. For laboratory studies, we simulate similar conditions for a homogenous medium (i.e., plexiglas) as in the numerical experiments. We record the signals obtained from propagating ultrasonic waves along samples with and without a fracture which is inclined at an angle of 45°.

The preliminary experimental results of an incident S-wave indicate that the fracture indeed leads to resonance effects. Figure 1a) and 1b) present the spectrograms of receiver time signals of the intact sample and the fractured sample, respectively, at a source frequency of 1 MHz. The presence of the fracture seems to trigger a possible resonance at low frequencies. Figure 1b) indicates a persistent low-frequency signal

(150 μs onwards). The average frequency of this fracture-related effect is approximately at 0.1 MHz. The laboratory results are in line with numerical studies (Frehner, 2014) even though there is a slight difference between the experimental setup and the numerical setup. By comparing numerical modeling (Frehner and Schmalholz, 2010; Frehner, 2014) and experimental results we aim to extract information about the fractures from the recorded seismic signals.

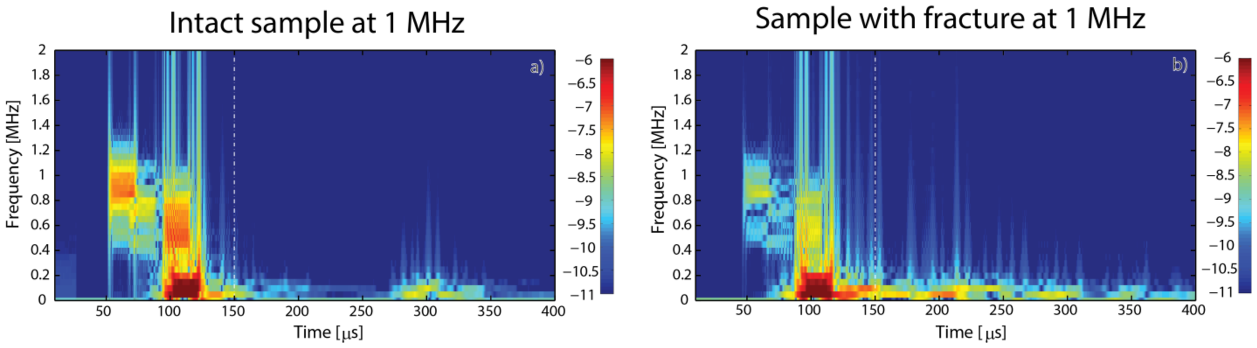

Figure 1. Spectrograms of receiver time signal of an S-wave propagating through a) the intact sample and b) the fractured sample with a source frequency of 1 MHz.

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