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Signature of seismic wave attenuation during fracture network formation

Auke Barnhoorn (1), Alimzhan Zhubayev (1), Maartje Houben (2), Nico Hardebol (1), and David Smeulders (3)

(1) Delft University of Technology, Department of Geoscience and Engineering, Delft, The Netherlands (auke.barnhoorn@tudelft.nl), (2) Utrecht University, Faculty of Geosciences, Utrecht, The Netherlands, (3) Eindhoven University of Technology, Department of Mechanical Engineering, Eindhoven, The Netherlands

Seismic waves are significantly affected by the presence of fractures and faults. Fractures alter the arrival time of a seismic wave and the amplitude of the seismic wave. Attenuation of a seismic wave is the reduction of wave amplitude due to the presence of e.g. fractures. Attenuation of acoustic compressional P- and shear S-waves have been measured in laboratory studies on different rock types. These studies generally show a decrease in attenuation with an increase in stress. This decrease in attenuation is attributed to progressive crack closure of pre-existing cracks. The stress-dependent decrease in attenuation reported in these studies all occur within the elastic deformation field, i.e. below yield stress levels and thus no additional cracks/micro-fractures have yet been formed.

At stress levels just above the yield strength the first fractures start to form. With increasing stress, fractures nucleate, grow and coalesce until a connected network of fractures has developed at which failure of the rock sample occurs. The change in attenuation during the fracturing process however has seldom been investigated. In analogy to fracture closure, where attenuation generally decreases, fracture formation should cause again an increase in attenuation.

Here we report an experimental study on shales from Whitby (UK), where s-wave attenuation was measured in the laboratory during an increase in stress towards fracture formation until complete failure of the shale samples. Before yield stress conditions, as expected an increase in stress caused a gradual decrease in attenuation. At the transition from elastic to inelastic deformation behaviour, the first microfractures start to form and attenuation starts to increase again. This reversal in attenuation behaviour could potentially be used as an indicator that failure of a rock mass under stress is imminent (imminence of seismicity). The measured seismic velocities do not depict the transition from elastic to inelastic deformation behavior. After peak stress conditions, a fully connected network of fractures is gradually formed and attenuation of the s-waves starts to be more complex. Changes in attenuation depend here on how individual fractures connect with each other and thereby influence the seismic waves.