CHAPMAN Samuel A. (2017) : Experimental characterization and analysis of fluid related seismic attenuation mechanisms in porous materials

Abstract

The amplitude of a seismic wave decays as it propagates through the earth. One reason why the signal decays is simply due to the geometrical spreading out of the energy of the wave over an expanding surface area. However, the signal also decays because part of the energy is converted into heat. This conversion of energy is referred to as intrinsic attenuation and is commonly defined as the ratio between the energy dissipated and the average energy carried by the wave. In practical terms, the energy decay of seismic waves, limits our ability to resolve the structure of the subsurface, but at the same time the process by which the signal decays can also provide us with additional information about the subsurface. Especially when fluids are present in the pore space of a rock, intrinsic attenuation can be considerable. In fluid saturated rocks there are a number of physical attenuation mechanisms. Of particular interest are various forms of wave-induced fluid flow (WIFF) because they are sensitive to the hydro- mechanical properties of the rock, which are difficult to characterise in the field. Another mechanism that can also potentially attenuate seismic waves is the wave-induced gas exsolution dissolution (WIGED) of micrometric bubbles in a liquid saturating the rock pores.

To better understand these mechanisms I performed laboratory experiments on partially and fully saturated rock and synthetic porous samples. The forced oscillation method was used to measure the frequency-dependent attenuation and the associated stiffness modulus dispersion at seismic frequencies. In Chapter 2 I looked at the impact of partial water saturation achieved by imbibition on the extensional mode attenuation and Young's modulus of a Berea sandstone sample. The qualitative analysis of the results found that the observed frequency dependent attenuation was consistent with mesoscopic WIFF in response to a heterogeneous distribution of the water and air in the pore space of the sample. In Chapter 3 I looked more closely at the impact of the fluid distribution on the frequency dependence of the measured attenuation. By changing from a heterogeneous distribution of mesoscopic gas patches to a homogeneous distribution of pore scale gas bubbles in the water, I observed a significant steepening of the high-frequency asymptote of the attenuation. A possible explanation for this change in scaling was a transition from mesoscopic WIFF to WIGED. In Chapter 4 I performed measurements on a synthetic sample made of sintered glass beads, again looking at the influence the degree and method of fluid saturation has on the frequency dependent attenuation. The results of these measurements provided additional support for WIGED as a possible new attenuation mechanism at seismic frequencies. In Chapter 5 the focus shifted to studying seismic attenuation in fully saturated Berea sandstone, again using the forced oscillation method, but in this case measuring also the bulk and shear attenuation modes and the corresponding moduli. In the considered frequency range I observed frequency dependent attenuation in response the drained-undrained transition and squirt flow. Both are forms of WIFF, however the drained-undrained transition is in response to the samples boundary conditions and squirt flow arises from fluid flow between compliant cracks and grain contacts and stiff pores.

The observations presented in this Thesis improve the understanding of the various attenuation mechanisms in partially and fully fluid saturated rocks. Especially when the rock is partially saturated, the experiments show not only the impact of the fluid distribution on the frequency dependence of a particular attenuation mechanism, but also the interplay between the different mechanisms. The Thesis will hopefully also provide an impetus for continued research into the attenuation mechanisms found in partially saturated rocks.