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Seismic wave attenuation due to fluid pressure diffusion at the mesoscopic scale: an experimental and numerical study

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Monitoring of the subsurface with seismic methods can be improved by better understanding the attenuation of seismic waves due to fluid pressure diffusion (FPD). In porous rocks saturated with multiple fluid phases the attenuation of seismic waves by FPD is sensitive to the mesoscopic scale distribution of the respective fluids. The relationship between fluid distribution and seismic wave attenuation could be used, for example, to assess the effectiveness of residual trapping of carbon dioxide (CO2) in the subsurface. Determining such relationships requires validating models of FPD with accurate laboratory measurements of seismic wave attenuation and modulus dispersion over a broad frequency range, and, in addition, characterising the fluid distribution during experiments. To address this challenge, experiments were performed on a Berea sandstone sample in which the exsolution of CO2 from water in the pore space of the sample was induced by a reduction in pore pressure. The fluid distribution was determined with X-ray computed tomography (CT) in a first set of experiments. The CO2 exosolved predominantly near the outlet, resulting in a heterogeneous fluid distribution along the sample length. In a second set of experiments, at similar pressure and temperature conditions, the forced oscillation method was used to measure the attenuation and modulus dispersion in the partially saturated sample over a broad frequency range (0.1 - 1000 Hz). Significant P-wave attenuation and dispersion was observed, while S-wave attenuation and dispersion were negligible. These observations suggest that the dominant mechanism of attenuation and dispersion was FPD. The attenuation and dispersion by FPD was subsequently modelled by solving Biot's quasi-static equations of poroelasticity with the finite element method. The fluid saturation distribution determined from the X-ray CT was used in combination with a Reuss average to define a single phase effective fluid bulk modulus. The numerical solutions agree well with the attenuation and modulus dispersion measured in the laboratory, supporting the interpretation that attenuation and dispersion was due to FPD occurring in the heterogenous distribution of the coexisting fluids. The numerical simulations have the advantage that the models can easily be improved by including sub-core scale porosity and permeability distributions, which can also be determined using X-ray CT. In the future this could allow for conducting experiments on heterogenous samples.