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Seismic wave attenuation and dispersion due to two-phase fluid saturation: Laboratory measurements and numerical simulations based on X-Ray CT

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The integration of poromechanical experiments under X-ray computed tomography with numerical simulations could improve the modeling of intrinsic attenuation of seismic waves by fluid pressure diffusion (FPD). This could lead to improvements in the monitoring of carbon dioxide storage sites where the sensitivity of the attenuation of seismic waves by FPD to the saturation and spatial distribution of the fluids could be used to assess residual trapping in a storage formation. However, this requires validating models of FPD with accurate measurements of seismic wave attenuation and modulus dispersion over a broad frequency range, as well as, parameterizing the fluid distribution during experiments.

Experiments were performed on a Berea sandstone sample where CO2 was allowed to exsolve from water following a reduction in pore pressure. The fluid distribution was determined with X-ray computed tomography (CT) in a first set of experiments. The CO2 exsolved predominantly near the outlet, resulting in a heterogeneous fluid distribution along the sample length. In a second set of experiments, at comparable pressure and temperature conditions, we investigated the attenuation and modulus dispersion in the partially saturated sample over a broad frequency range (0.1 - 1000 Hz) by applying force axial oscillations and measuring the stress-strain response of the sample. We observed significant attenuation and dispersion in the extensional and bulk deformation modes, with the Young's and Bulk modulus falling between the low frequency Gassmann-Wood limit and the high frequency Gassmann-Hill limit. No frequency dependent attenuation and dispersion was observed in the shear modulus. These observations are consistent with FPD at the mesoscopic scale in a mechanically isotropic rock.

The attenuation and dispersion by FPD were 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. The approach can be extended to include sub-core scale porosity and permeability distributions, which can also be determined from multiphase core flooding experiments in combination with X-ray CT. In the future this could allow for conducting experiments on heterogenous samples and accurately relating fluid distribution to the attenuation of seismic waves. Such an advancement will however require the development of a new experimental setup capable of measuring the quasi-static stress-strain response of samples concurrently with X-ray CT.

Participation

In-Person

References

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Primary authors: Dr CHAPMAN, Samuel (Ecole Normale Supérieure / CNRS UMR 8538); Dr BORGOMANO, Jan V. M. (TotalEnergies); Dr QUINTAL, Beatriz (University of Lausanne); BENSON, Sally (Stanford University); Dr FORTIN, Jerome (Ecole Normale Supérieure / CNRS UMR 8538)

Presenter: Dr CHAPMAN, Samuel (Ecole Normale Supérieure / CNRS UMR 8538)

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