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Effects of permeability barriers and pore fluids on S-wave attenuation

B. Quintal and M. Frehner
The Rock Physics Network, ETH Zurich, Switzerland (www.rockphysics.ethz.ch, beatriz.quintal@erdw.ethz.ch)

We study seismic attenuation of P- and S-waves caused by the physical mechanism of wave-induced fluid flow at the mesoscopic scale. Stress relaxation experiments are numerically simulated by solving Biot's equations for consolidation of two-dimensional poroelastic media with finite-element modeling. The experiments yield time-dependent stress-strain relations that are used to calculate the complex moduli from which frequency-dependent attenuation is determined. Our model consists of periodically distributed circular or elliptical heterogeneities with much lower porosity and permeability than the background medium, which contains 80% of the total pore space of the medium. This model can represent a hydrocarbon reservoir, where the porous background is either fully saturated with oil or gas, and the low porosity regions are always saturated with water.

Three different saturation scenarios were considered: oil-saturated (80% oil, 20% water), gas-saturated (80% gas, 20% water), and fully water-saturated medium. Varying the dry bulk and shear moduli in the background and in the heterogeneities, a consistent tendency is observed in the relative behavior of the S-wave attenuation among the different saturation scenarios. First, in the gas-saturated media the S-wave attenuation is very low and much lower than in the oil-saturated or in the fully water-saturated media. Second, at low frequencies the S-wave attenuation is significantly higher in the oil-saturated media than in the fully water-saturated media. The P-wave attenuation exhibits a more variable relative behavior among the different saturation degrees, but one tendency is observed: At low frequencies the P-wave attenuation is higher in the oil-saturated media than in the fully water-saturated media.

Based on the mechanism of wave-induced fluid flow and on our numerical results we suggest that the S-wave attenuation could be used as an indicator of fluid content in a reservoir, in addition to the P-wave attenuation. We also studied the influence of impermeable barriers in the medium. No effect is expected for P-wave attenuation. However, the impermeable barriers cause a significant increase in S-wave attenuation. This suggests that S-wave attenuation could be an indicator of permeability changes in, for example, fracturing operations.