Evidence of seismic attenuation due to air bubbles in weak sandstone.

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Introduction

Seismic wave attenuation can be related to wave-induced fluid flows in some specific porous media, especially in case of partial saturation (Pride et al., 2004). When a seismic wave is travelling through the porous medium, the induced pressure gradients in the gas and liquid phases are equilibrating with different inertial properties creating strong attenuation at given frequencies. The patchy saturation theory developed by Pride et al. (2004) relates the observed attenuation of seismic waves with the presence of gas spheres embedded in the medium saturated by a less mobile liquid. This abstract presents analysis of ultrasonic data in weak sandstone and correlates the observation with patchy saturation modelling.

Methods and data

Castlegate sandstone is constituted of 70% of quartz and 30% of feldspar and rock fragments with 26.8% porosity. Ultrasonic measurements were performed on 1.5"x3" plugs, with transmission setups (Fjær, 2009). We consider the P-wave records at a hydrostatic pressure of 10 MPa. The spectra for the first arrivals are given in Figure 1 for dry and water "saturated" samples. The amplitude of the waveforms for the water "saturated" sample is lower than the one for the dry sample. The spectra are similar for both samples until 200-250kHz but with a big drop around 350kHz for the water "saturated" sample. This drop in the spectra is interpreted as larger attenuation above 350kHz and probably due to residual air bubbles in the water sample. Using the P- and S-wave ultrasonic velocities and density, we estimate the rock frame properties (dry bulk and shear modulus K_D and G_D and cementation factor m) using a rock physics inversion based on extended Biot-Gassmann theory (Dupuy et al., 2016). We use the rock frame properties derived from the dry sample to estimate water saturation and bubble radius using the patchy saturation theory (Pride et al., 2004). Finally, rock physics modelling using patchy saturation theory allows computing P-wave quality factor versus frequency to compare with observed spectra.

Results

Estimation of rock frame properties based on dry sample parameters (V_P = 2895 m/s, V_S = 1807 m/s and ρ = 1940 kg/m^3) gives a range of low misfit values with the best results being K_D = 5.6 GPa, G_D = 6.84 GPa and m = 1.52. For the air-water sample, the input are: V_P = 2973 m/s and V_S = 1574 m/s. The inversion of water saturation and bubble radius allow selecting a set of models with low misfit (less than 1 %). These models have a range of water saturation from 84.5% to 97.3% and a range of bubble radii from 0.325 to 1.89 cm. Models with larger bubble radii have been excluded in order to be consistent with the sample size. Given the resonance frequency observed on spectral data (Figure 1, around 350 kHz) and using Anderson and Hampton (1980) model, we calculate an approximated value of bubble radius equal to 1.7 cm, which is consistent with patchy saturation model. Using rock physics forward modelling, we compute P-wave quality factors versus frequency (Figure 1). The value of the quality factor is lower for air-water samples (patchy saturation) than for dry sample and it is decreasing with frequency. The attenuation for these models stays strong at higher frequencies (Q_P reaching 15) while the value of the quality factor for the dry sample is much higher (from 200 to 1200).

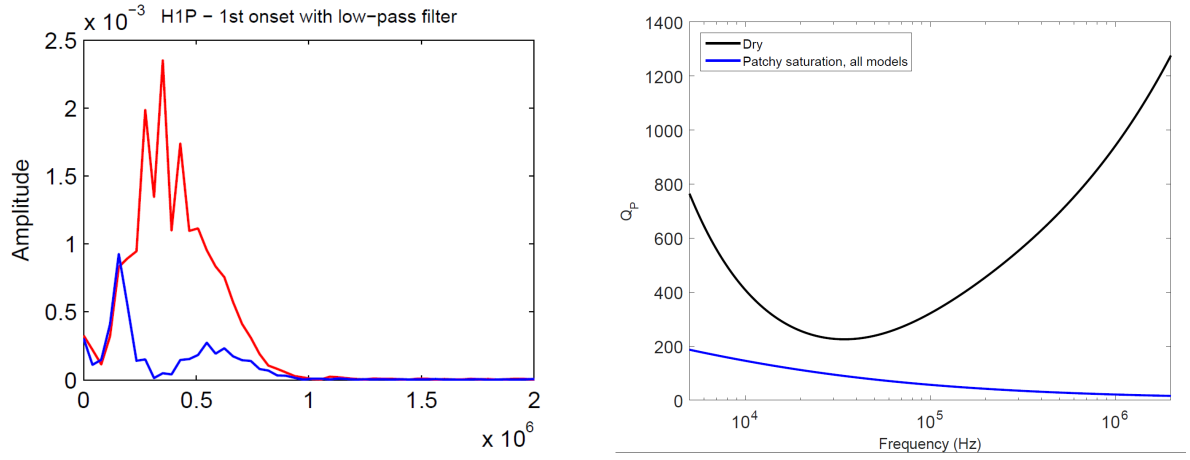

Figure 1: (Left) Spectra of first onsets (between 10 and 30 µs). Red lines: dry sample and blue lines: water-air sample. The data have been filtered with a low-pass filter using a cut-off frequency of 1 MHz. (Right) P-wave quality factor Q_P versus frequency computed for dry samples and partially saturated samples.

Conclusions

We observe a strong correlation between the frequency drop seen in ultrasonic spectral data and the modelling of P-wave quality factor using patchy saturation theory. The quality factor has lower values (large attenuation) when air bubbles are present and especially when the frequency is increasing.

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