Elastic dispersion in fluid-saturated limestones: experimental and modelling results.

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Introduction

Fluid-saturated rocks are known to be dispersive, making it difficult to directly compare the elastic properties deduced from ultrasonic (1 MHz) and seismic/sonic log measurements (10 Hz – 10 kHz). The elastic properties' dispersions are due to transitions between fluid-flow regimes at different scales. In fully saturated sandstones, the drained/undrained transition at the REV scale and the undrained/unrelaxed (squirt-flow) transition at the crack scale need to be considered (e.g. Pimienta et al., 2016b). In carbonate rocks, however, the high variability of porosity types makes it challenging to predict the coupling between the saturating fluid and the complex microstructure over the frequency range.

In this study, we present experimental results, over a large frequency range, of dispersion in two clean limestones: a Lavoux and a coquina limestone. The results are compared to a simple model based on effective medium theory, which takes into account both the drained/undrained and the undrained/unrelaxed transition.

Methods

The experimental results were obtained in a triaxial cell, using both stress-strain method and ultrasonics (Borgomano et al., 2016). The apparatus enables to do hydrostatic oscillations up to 0.4 Hz, and axial oscillations up to 100 Hz (Pimienta et al., 2015a & 2015b). After the measurements in dry conditions, two different saturating fluids were used: glycerine and water. The viscosity contrast between those fluids (3 orders of magnitude) enables to characterize the sample over a larger apparent frequency range.

The dispersion model is based on a model from Adelinet et al. (2011), combined with the drained/undrained diffusion model from Pimienta et al. (2016a). It is designed to predict properties of a porous and microcracked rock, with a crack family of a unique aspect ratio. In liquid-saturated conditions, the frequency dependence of the effective moduli is modelled using a "virtual fluid modulus" that is frequency dependent, similarly to the squirt-flow model from Gurevich et al. (2010). The model uses a limited number of input parameters, and is confronted to the experimental results.

Results

Different behaviours are observed from the pressure and frequency dependences of the rocks elastic properties, and a differentiation is observed between the limestone samples. For the Lavoux limestone, no dependence to pressure is observed. But, for the coquina limestone, a large increase in elastic moduli is observed as pressure increases, implying the presence of microcracks in the rock sample. Over the frequency range, the two rocks exhibit only the drained/undrained transition, and, contrary to sandstones, no squirt-flow is observed (Fig. 1).

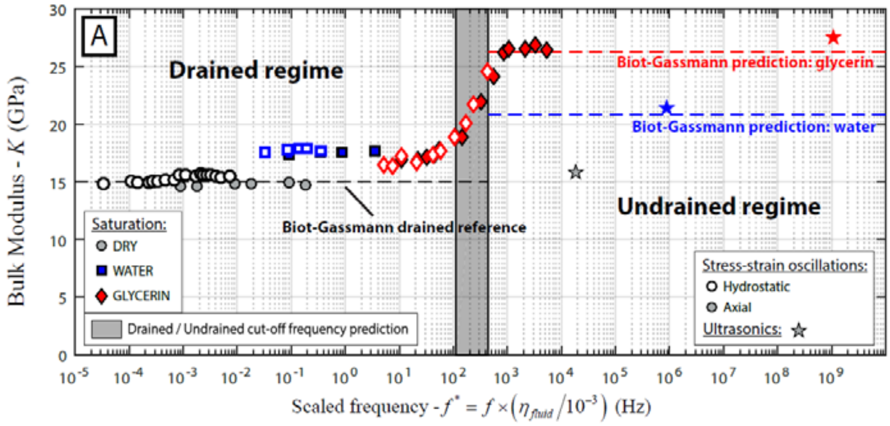

Figure 1: Dispersion results of the Bulk Modulus (K) of a Lavoux limestone, using measurements from the two set-ups of hydrostatic and axial oscillations. Only a drained/undrained transition is observed for this sample. Figure modified from Borgomano et al. (2016).

As confirmed by the model, no squirt-flow is indeed expected for the Lavoux limestone, and the model predictions fit well the experimental results. However, owing to the existence of microcracks (as inferred from the pressure dependence), squirt-flow is expected to occur in the coquina limestone. For the sandstone samples, the model fits the data.

Conclusion

New experimental results have been obtained in fluid-saturated limestones. No squirt-flow is observed over the frequency range. A new model is developed to understand the measurements. The model predictions quantitavely explain the data for the sandstones and one limestone sample. However, further investigations are needed to explain the absence of fluid-flow for the second limestone sample.

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