Solid substitution: theory versus experiment

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Introduction

Gassmann fluid substitution is widely used in geophysical practice. In the last few years a topic of fluid/solid substitution has emerged, where the substances filling the pore space can be solids, fluids, or visco-elastic materials (Ciz and Shapiro, 2007, Saxena and Mavko, 2014, Glubokovskikh *et al.*, 2016). This topic originally emerged in the context of rocks saturated with heavy oil (Ciz and Shapiro, 2007, Makarynska *et al.*, 2010). Heavy oils are viscoelastic substances, which are nearly-solid at room temperatures and/or high frequencies, but approach fluid behaviour upon heating or if measured at very low frequencies. Solid substitution cannot be accomplished with the Gassmann theory because the finite rigidity of the pore fill (either solid or viscoelastic) prevents pressure communication throughout the pore space, which is a key assumption of the Gassmann theory. However experimental verification of theoretical solutions using heavy oils is difficult because it requires precise measurements of the properties of both the rock saturated with the heavy oil, and the oil itself., which is very challenging (Behura *et al.*, 2007). Furthermore, solid substitution has potential applications beyond heavy oil; e.g. for modelling the effect of mineral precipitation in the pore space (Saxena *et al.*, 2016). In this paper we explore applicability of solid substation techniques by using asandstone saturated with an actual solid substance, Octadecane.

Experiment

Octadecane ($CH_3(CH_2)_{16}CH_3$) is a hydrocarbon with a melting point of 28°C, making it convenient to use in the lab in both solid and fluid form. Our approach is to measure a dry sandstone sample, then saturate it with liquid Octadecane at 35°C, measure, cool it to 20-25°C and measure again. The dry properties can be used to obtain parameters necessary for fluid and solid substitution. The properties of Octadecane itself has also been measured. In liquid form at 35°C it has compressional velocity of 1370 m/s and density of 0.8 g/m^3. In solid state at 23°C it has P- and S- velocities of 2610 and 1204 m/s respectively, and density of 0.777 g/m^3.

Results

The ultrasonic measurements and theoretical predictions are summarised in Figure 1. We see that moduli of the dry sandstone exhibit significant pressure dependency, which is greatly reduced for the solid filled rock. Also the prediction of the Gasmann theory and Ciz and Shapiro (2007) theory underestimate the velocities. This suggests that stiffening occurs due to substantial reduction of compliance of grain contacts by the solid infill. This effect can be accounted for by the solid squirt theory of (Glubokovskikh *et al.*, 2016).

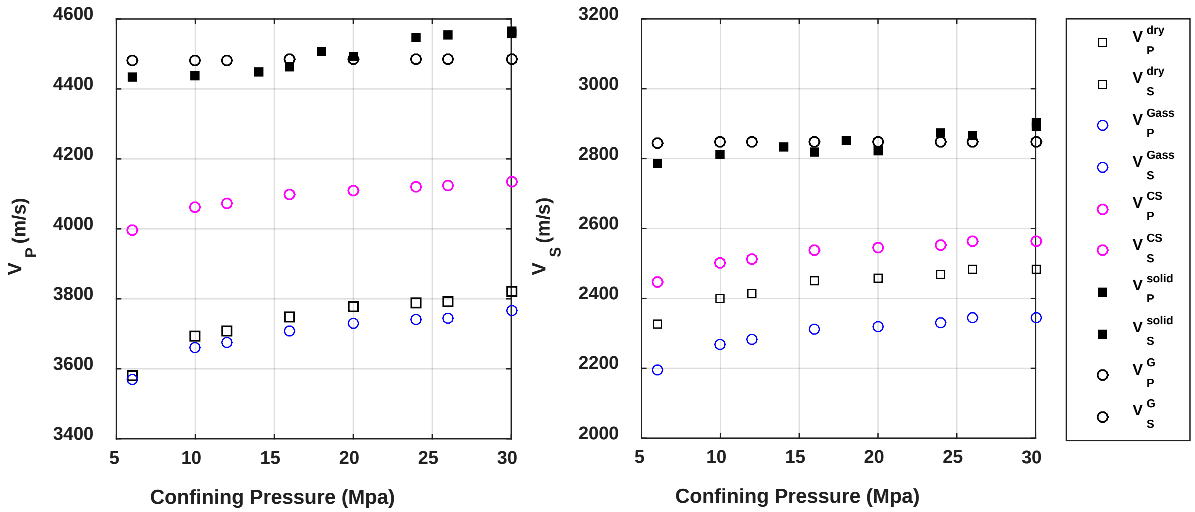

Figure 1. Measured ultrasonic P and S velocities of the sandstone sample in dry (open squares) and solid-saturated (filled squares) and predictions (circles) of the Gassmann theory (blue), Ciz and Shapiro (2007) theory (magenta) and solid squirt theory (black) with soft porosity of 0.01 and aspect ratio 0.1.

Conclusions

The results give direct evidence of the solid squirt effect and can be used to verify and calibrate theoretical solutions for rocks saturated with solid or viscoelastic substances. More definitive conclusions can be made by adding low frequency measurements of the sample saturated with the Octadecane in the liquid state.

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