Comparison of elastic properties of reservoir rocks in the field and the laboratory : link between seismic, sonic and ultrasonic measurements

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1) Introduction

Elastic wave propagation is commonly studied in geophysics for prospecting, to follow the exploitation of hydrocarbon reservoirs, or to study the effect of fluid injection (CO_2 storage). It can be difficult to compare elastic wave measurements in the laboratory to those in the field.

In the field, log wells tests are usually around the frequency range of 10 kHz where a typical lab measurement is done in the MHz range using ultrasonics. This is an issue when comparing these due to the dispersive nature of these porous materials.

Using forced axial oscillations first introduced by Batzle et al. (2006) there have been improvements in the range of frequencies at which samples can be tested. At ENS, piezoelectri actuators and pore fluid substitution allows a larger range of frequencies to be tested between 0.001 Hz to 1 MHz not inclusively.

This poster presents the elastic properties of a sample using well understood experimental methods and directly comparing these with well log data.

2) Sample

The sample that was tested is a presalt carbonate.

The sample and its X-ray scans can be seen in Figure 1 and 2. The sample is relatively homogeneous and belongs to the granular facies.

Figure 1: Picture of sample

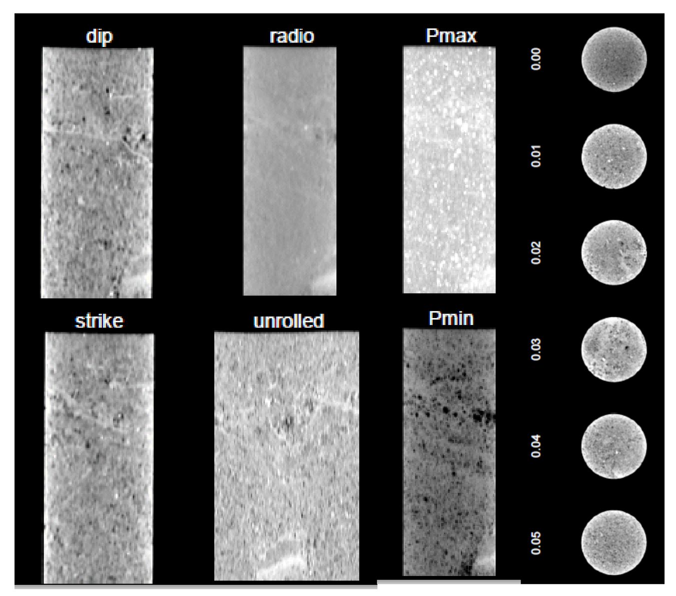

Figure 2: X-rays of sample

Four other samples were also collected from the same area with varying facies (shrub and coquina) and heterogeneities. This will allow us to study the dispersion of similar samples with different facies.

Sample Properties

Porosity (ϕ) = 16.8 %

Permeability (k) = 84 mDa

Mineral Composition= 95.3% Calcite, 4.7% Quartz

Reservoir Properties = Pore Pressure 63 MPa, Confining Pressure 90 MPa, Deviatoric Stress 6 MPa

3) Laboratory Setup

The TOP industrie triaxial cell:
- *Cell pressure range:* **0 - 100 MPa**
- *Axial pressure range:* **0 - 700 MPa**
- *Cell Temp. range:* **20 - 100 °C**
- *acquisition up to* **14** *strain gauges*
- *and with* **1** *piezoelectric oscillator*
- *and with* **4** *ultrasonic transducers*
- *P&S wave ultrasonic transducers along the length of the sample*

- *Other Characterizations:*

  Sample size: 40 mm diameter, 80 mm height
  Maximum sampling frequency 4 kHz
  350 ohms axial and radial strain gauges

- *Piezoelectric oscillator: PI - PICA Stack with 30* µm displ., 48 kN blocking force and 32 kHz free resonant frequency

- *Microvalves:* piloted microvalves in the end-platen to achieve either drained or purely undrained conditions for the pore fluid (dead volume of 20 µl when closed)

- When investigating the dispersion due to viscous fluid flow, frequency can be scaled by the fluid viscosity to extend the **apparent frequency** following: $f^* = f\frac{\eta_f}{\eta_0}$ → is for Brine in this case

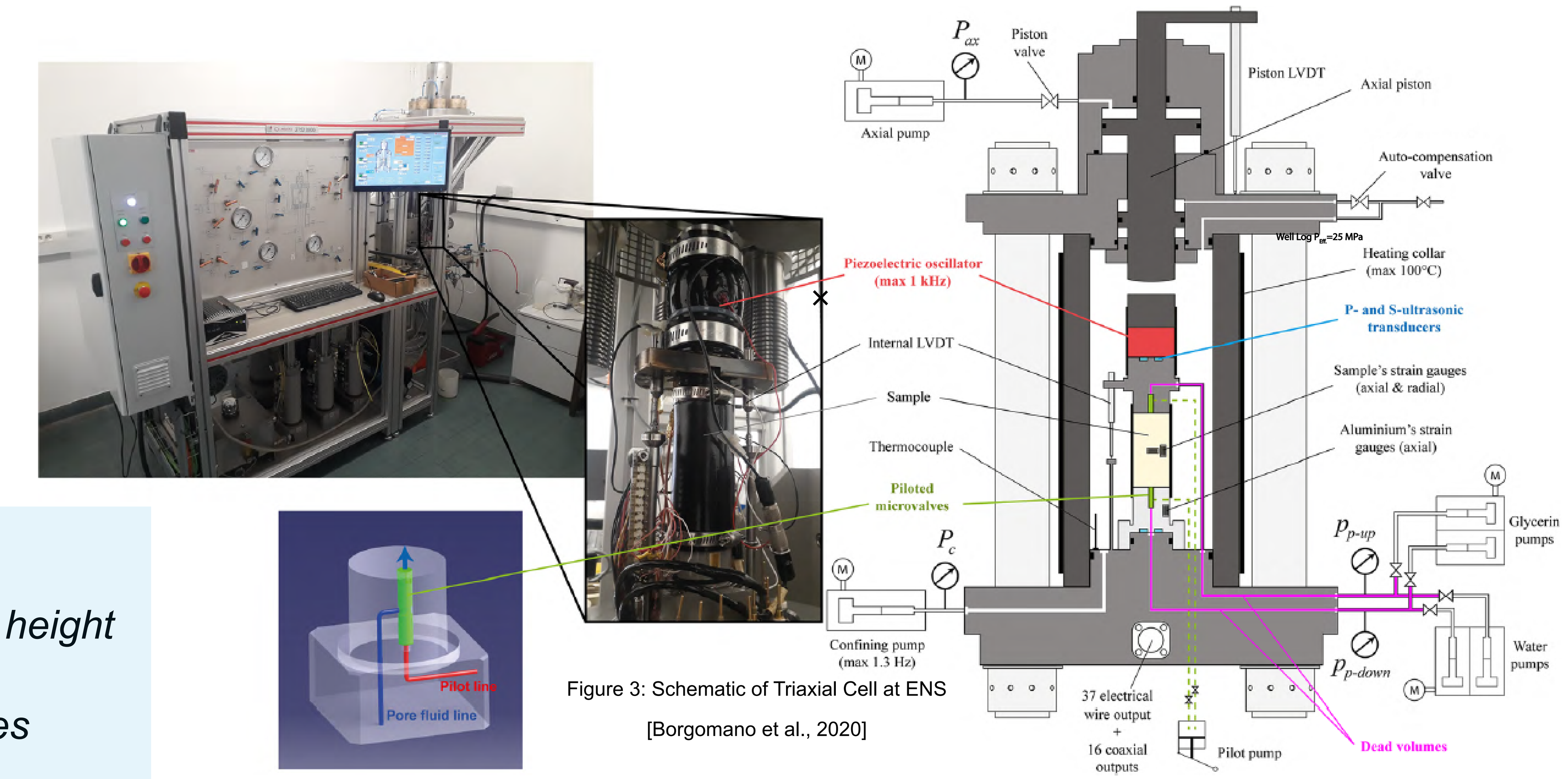

Figure 3: Schematic of Triaxial Cell at ENS [Borgomano et al., 2020]

	η (Pa*s)	K_f (GPa)
Water	0.00089	2.24
Brine	0.0018	3.7
Glycerin	1	4.36

Table 1: Dynamic viscosity and Bulk Modulus of pore fluids [Batzle and Wang 1992]

Method	*Measures*	*Frequency Range (Hz)*
Hydrostatic Oscillation	*K*	10^{-3} *to 1.3*
Axial Oscillation	*E , v*	10^{-2} *to* 10^{3}
Ultrasonics	v_p , v_s	10^{6}

Table 2: Summary of tests used, what they directly measure and their frequency

4) Forced Oscillations

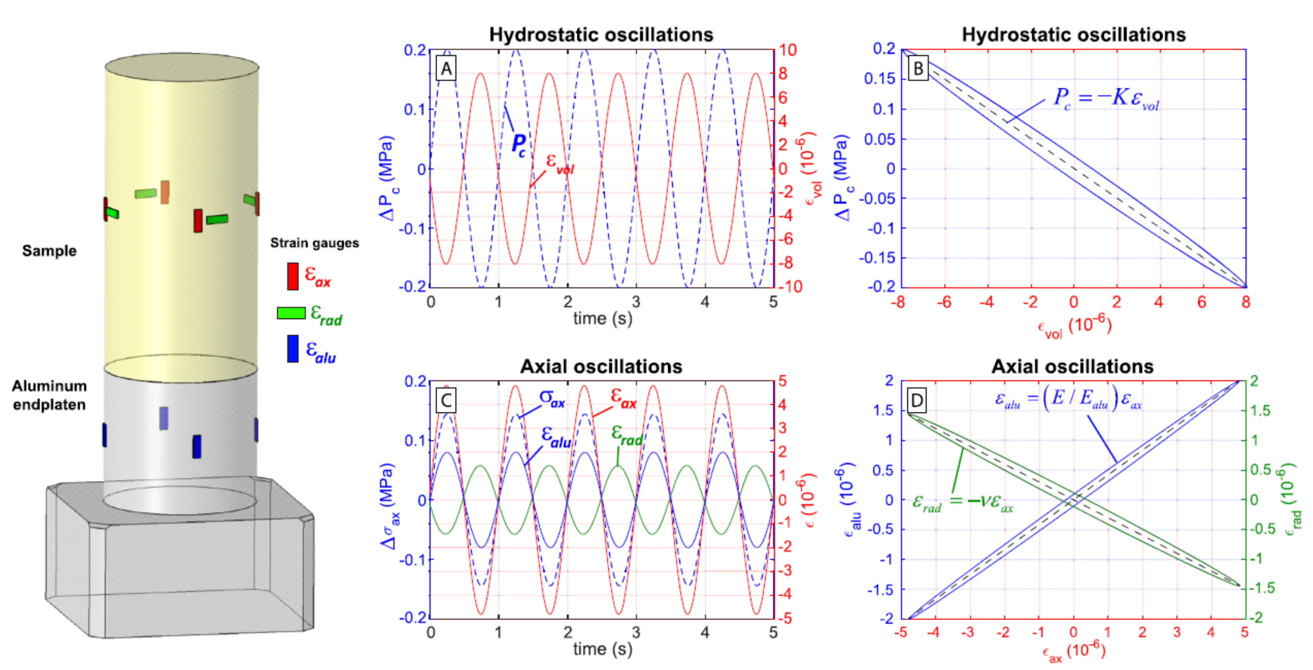

Figure 4: Strain gauge position (Left); Hydrostatic oscillations (A and B); Axial oscillations (C and D);[Borgomano et al., 2020]

Fast Fourier Transforms are used to find the stress and strain signals from the forced oscillations

Axial Calculations

$$E = \frac{\sigma_{alu}}{\varepsilon_{ax}} \qquad \nu = -\frac{\varepsilon_{rad}}{\varepsilon_{ax}}$$

Hydrostatic Calculations

$$\varepsilon_{vol} = \varepsilon_{ax} + 2\varepsilon_{rad} \qquad K = \frac{-P_c}{\varepsilon_{vol}}$$

Attenuation (inverse of quality factor) related to a complexe modulus M:

$$Q^{-1} = \frac{\mathrm{Im}(\bar{M})}{\mathrm{Re}(\bar{M})} = \tan(\varphi_\sigma - \varphi_\varepsilon)$$

5) Preliminary Results

The sample was tested at effective pressures of ***5, 15*** *and* ***25 MPa****. The maximum effective pressure was recorded at 27 MPa. The sample is isotropic (88.5 %).*

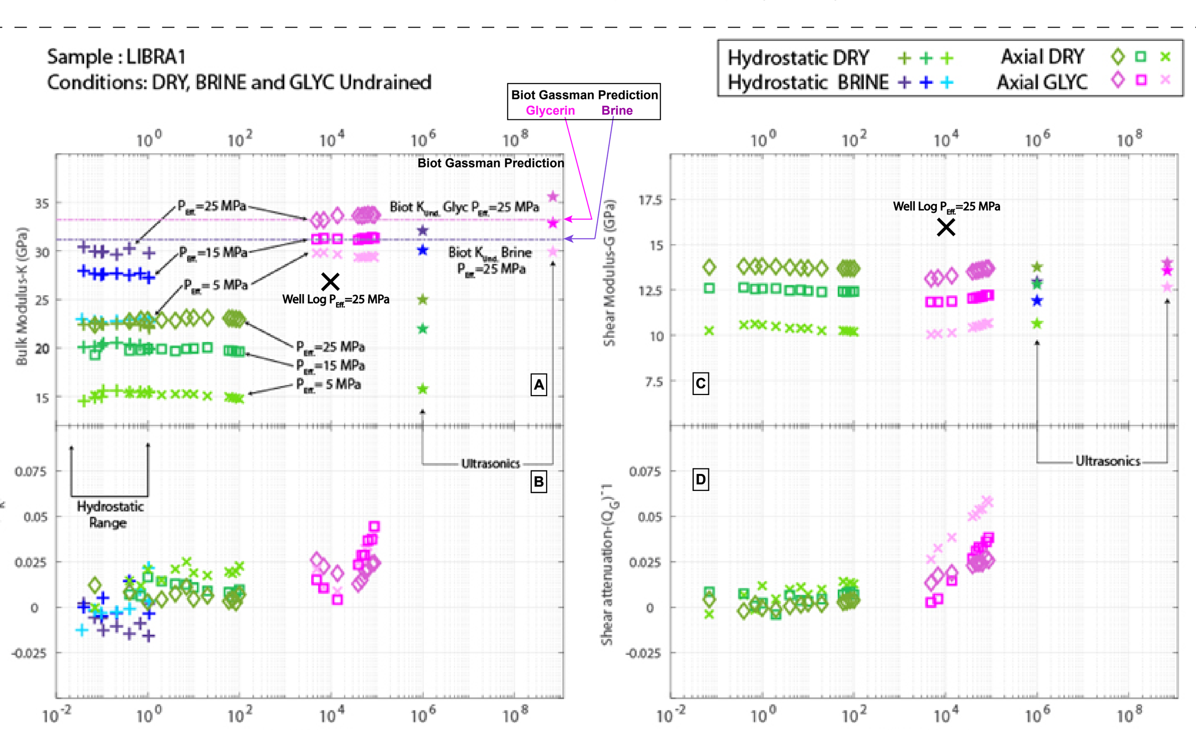

Figure 5: Bulk Modulus (A), Bulk Attenuation (B), Shear Modulus (C) and Shear Attenuation (D) versus frequency for dry, brine and glycerin saturated conditions of sample LIBRA 1

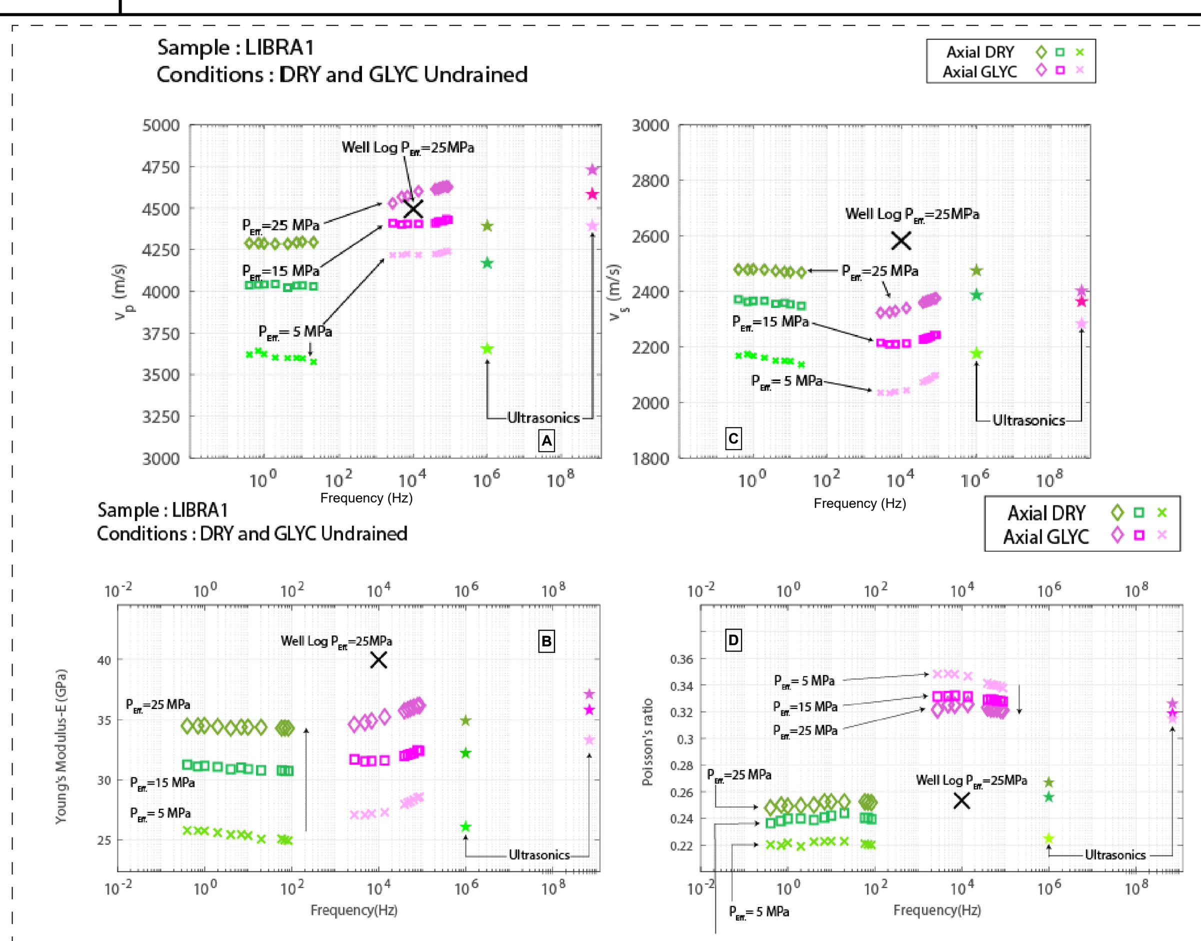

Figure 6: Bulk Modulus (A), Young Modulus(B), Shear Modulus (C) and Poisson's ratio (D) versus frequency for dry, brine and glycerin saturated conditions of sample LIBRA 1 and well log data comparison

6) Conclusions

- Biot Gassmann predicts the Undrained modulus
- There is some evidence of dispersion around the well log frequencies. This may be due to squirt-flow relative to microcracks or grain to grain contact.
- The lab results are similar to the log well data with some discrepancies which may be due to the uncertainties of the pore fluid pressure.

7) Perspectives

- More tests needed at higher effective stresses and in situ stresses
- Complete testing on all 5 samples with different facies, compositions and heterogeneities

8) Bibliography

Acknowledgements:
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