Ultrasonic measurements in fluid-saturated carbonate rocks at different confining pressures: when is Biot-Gassmann's equation valid?

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Abstract:

In this study, we investigate the effect of confining pressure and fluid substitution on ultrasonic P- and S-wave velocities in lacustrine carbonate samples. The samples come from cores extracted between 3620 and 3640 meters depth in the Yacoraite Formation (Salta rift basin, Northwestern Argentina). The selected samples include laminated microbialites and oolitic grainstones and therefore display very different microstructures.

In a first step, three hydrostatic cycles (up to a confining pressure of 60 MPa with a constant pore pressure of 1.5 MPa) are performed using saturating fluids with different bulk modulus: nitrogen, brine, and ethylene glycol. Ultrasonic P- and S-wave velocities are measured for each 5 MPa confining pressure increment using double P and S transducers with a central frequency of 500 kHz. In a second step, the differential pressure is maintained constant at 55 MPa and the ultrasonic velocities are measured for an extended set of successively miscible saturating fluids (ethylene glycol, methanol, ethanol, heptane, ethanol, brine). The ultrasonic waveforms are analyzed using two different approaches: i) the classical first-break picking and ii) the phase spectral ratio method. The use of the phase velocity minimizes the effect of heterogeneity by providing homogenized velocities more representative of the sample macroscopic behavior[1].

We first illustrate the pressure sensitivity of P- and S-wave velocities, as expected higher for nitrogen than for brine and ethylene glycol. Then, recalling that ultrasonic velocities in fluid saturated rock provide unrelaxed moduli, whereas by definition Biot-Gassmann's equation predicts relaxed moduli[2], we use the full fluid substitution sequence to check the applicability of Biot-Gassmann's equation at high confining pressure, when microcracks are closed and the unrelaxed moduli are equal to the relaxed moduli. Third, we discuss the dispersion between ultrasonic measurements and Biot-Gassmann's prediction at lower confining pressure. Finally, we address the difference between first-break velocities and phase velocities based on microstructure data and the sedimentological and diagenetic features of the samples studied.

[1] Bemer, E., Hamon, Y. and Adelinet, M. (2019) Consistent experimental investigation of the applicability of Biot-Gassmann's equation in carbonates. *Geophysics*, **84(4)**, WA97–WA113, https://doi.org/10.1190/GEO2018-0631.1.
[2] Fortin, J., Pimienta, L., Guéguen, Y., Schubnel, A., David, E.C. and Adelinet M. (2014) Experimental results on the combined effects of frequency and pressure on the dispersion of elastic waves in porous rocks. *The Leading Edge*, **33(6)**, 648-654, https://doi.org/10.1190/tle33060648.1.