Pore aspect ratio estimation using well log data for velocity modeling

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Abstract

Rock physics models based on inclusion theory, such as Kuster-Toksoz, DEM, and T-Matrix, which incorporate different pore types, are preferred for velocity modeling of carbonate rocks. These methods assume a homogeneous, isotropic host medium (rock matrix) containing inclusions (pores) with different pore aspect ratios. As a geometric attribute of the pore shape, the aspect ratio of the pores is assumed to control stiffness and velocities of the carbonate rock. Kumar and Han (2005) developed a method to estimate the pore aspect ratio for modeling the P-wave velocity log. Mirkamali et al. (2020) extended this methodology to model P- and S-wave velocity logs with optimal aspect ratio. The authors' proposed method defines three types of pores that make up the pore structure of carbonate rocks: crack (micropores), reference (interparticle), and stiff (spherical) pores. Interparticle pores are the most significant fraction assumed to be the primary porosity. Spherical pores tend to be stiffer and more resistant to pressure changes. Finally, micropores tend to be flatter and sensitive to stresses.

The process to estimate the pore aspect ratio is based on calibrating the reference velocities from Wyllie Time-Average Equation (reference pores) and the Hashin-Shtrikman bounds (stiff for the upper limit and cracks for the lower limit) using DEM. Estimating reference pores to calibrate the Wyllie Time-Average velocity has high precision. The stiff and crack pores process requires precise information on the mineral elastic moduli to model the Hashin-Shtrikman bounds' velocities. Without precise information on the mineral moduli, estimating stiff and crack pores to calibrate the velocity from DEM to Hashin-Shtrikman bounds has low accuracy. The lower-limit velocity shows values around 2.5 – 2.8 km/s, and the upper-limit velocity shows 5.25 – 6.25 km/s. Estimating the aspect ratio to model these values shows several spikes, even using the extreme variation of the pore aspect ratio (0.001 or 0.999). The application of extreme pore aspect ratio values reflects in the estimation of the percentage of occurrence for each pore type and has low precision to model the well log velocity.

Therefore, we proposed a method for modeling the elastic moduli of the mineral (bluk and shear) using an inversion of the Gassmann equation for the dry bulk modulus from a dry rock model and an optimization process to determine the Hashin-Shtrikman bounds correctly. Instead of using the Wyllie velocity as a reference, we use the average of Hashin-Shtrikman because it follows the trend of the modeled mineral elastic moduli due to the optimization process. Since DEM involves high computational costs, we propose to use the model of Keys and Xu (2002) as another inclusion method. These modifications to the original method proposed by Kumar and Han, based on initial tests, can result in a more reliable estimate of pore structure, elastic moduli, and velocity prediction from well log data. This new method can be applied to the characterization of rocks with complex pore geometry, as is the case with the Brazilian pre-salt hydrocarbonate reservoir.

References

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