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 in carbonate rocks. These methods assume a homogeneous, isotropic host medium (rock matrix) containing inclusions (pores) with different pore aspect ratio (AR). As a geometric attribute of the pore shape, the aspect ratio of the pores controls the stiffness and velocities of carbonate rock. The general approach is to define 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 control most of the stress sensitivity of the 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 their method to model P- and S-wave velocities using the optimal pore aspect ratio estimated from the data. The estimation assumes that velocities computed from Wyllie Time-Average Equation represent the rock composed exclusively by reference pores. Then, it is straightforward to find the best AR to model reference velocities. Similarly, the Hashin-Shtrikman lower and upper bounds are used to compute velocities representative of cracks and stiff pores. We found that calibrating the Wyllie Time-Average velocities with optimal AR for reference pores produces consistent results. On the other hand, the stiff and crack pores AR calibration process requires precise information on the mineral elastic moduli, which is not always available. Without this information, estimating stiff and crack ARs sometimes becomes unstable, too low or too high. In this case, the aspect ratio curve shows several spikes, even using extreme values of the pore aspect ratio (0.001 or 0.999). Furthermore, using extreme pore aspect ratio values affects the volume fraction for each pore type, sometimes failing 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 directly from the data. 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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