Characterization of Carbonate Reservoir Permeability Heterogeneity by Integrating Rock Physics Model, Core Measurement and Petrophysical Data

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A carbonate rock-physics velocity model that considers dominant factors including mixed mineral composition, grain size and pore structure is very important for carbonate reservoir characterization. Based on an extended Biot theory of poroelasticity, a simplified rock physics model is derived for carbonate rocks by defining elastic parameters called frame flexibility factors. These frame flexibility factors depend less on porosity than wave velocity does. They are not only related to pore structure type but also to solid/pore connectivity and grain size. This poroelasticity model has been successfully proven at the core-plug scale against measured core data for its effectiveness in quantifying pore structure. Using examples from a San Andres carbonate reservoir, Permian Basin, we illustrate that one of the frame flexibility factors is inverted from log petrophysical data tied by core measurements to characterize the effect of pore structure changes on sonic wave velocity and permeability in carbonate reservoir rocks.

Our study of a San Andres carbonate reservoir, Permian Basin, shows that for core samples at given porosity, the lower the frame flexibility factor, the higher the sonic wave velocity. A frame flexibility factor value of 3.85 could be used to populate permeability zones with different geological origin for the studied San Andres carbonate reservoir. Samples with frame flexibility factor <3.85 are either dolograinstone and dolopackstone with visible vuggy pores or tight dolowackstone. On the other hand, samples with frame flexibility factor >3.85 are dolopackstone with dominant interparticle pores, dolowackstone or dolomudstone with microcrack pores. Using the frame flexibility factor, different porosity-velocity and porosity-permeability trends can be classified with clear geologic interpretation such as carbonate rock and pore structure types. The correlation coefficient between porosity and permeability is around 0.64 without the classification by frame flexibility factor, and it is improved up to 0.85-0.88 with frame flexibility factor indication.

New porosity-permeability relations with the classification by frame flexibility factor help to improve the prediction accuracy of reservoir permeability and delineate high-permeability zones in the San Andres reservoir, and could be useful for other similar carbonate reservoirs as well. They can be further used for seismic inversion of porosity and permeability in future work.