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Anisotropy characterization of coquinas through Thomsen parameters: implications for pre-salt reservoir modeling

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Introduction

The pre-salt carbonate reservoirs of Brazil, particularly coquinas, exhibit complex pore structures that challenge traditional reservoir characterization methods. These rocks are highly heterogeneous, with pore networks that influence fluid flow, mechanical properties, and seismic wave propagation. Understanding their anisotropy - how properties vary with direction - is crucial for accurate reservoir modeling. Digital Rock Physics (DRP), combined with numerical simulations, offers a powerful approach to analyze these complexities.

This study focuses on a coquina sample from the Morro do Chaves Formation, employing µCT imaging and computational modeling to assess fluid dynamics and poroelastic behavior, with particular estimating Thomsen's anisotropy parameters.

Methodology

The study utilized microcomputed tomography (µCT) to image a coquina sample (COQ-9) from the Sergipe-Alagoas Basin. The sample was analyzed using GeoDict software and its specialized packages (PoroDict, FlowDict, SatuDict, and ElastoDict) to simulate fluid flow and poroelastic properties. Two solvers were employed: The Analytical Formula (AF) solver, based on Voigt-Reuss bounds for isotropic approximations, and the Fast Fourier Transform (FFT) solver, which calculates effective elastic parameters.

The workflow included image preprocessing, porosity calculation, flow simulation, and elastic property estimation, including Thomsen's parameters (ε, δ, and γ), enabling a detailed examination of the sample's microstructure and anisotropy.

Results and Conclusions

The µCT analysis revealed a porosity of approximately 19.66%, closely matching laboratory measurements (18.63%). Flow simulations showed velocity variations, with higher velocities in pore throat regions. Small but non-zero values ($\varepsilon = 0.067$, $\delta = -0.064$, $\gamma = 0.053$) suggested mild directional dependence, likely due to pore network connectivity. Near-zero ε and γ, but a negative δ (-0.064), implying subtle velocity variations at oblique angles. The weak anisotropy ($\varepsilon, \delta, \gamma < 0.1$) means that coquinas behave nearly isotropically, simplifying seismic interpretation. The negative δ suggests that wave propagation slows slightly at intermediate angles. Shear-wave splitting ($\gamma > 0$) hints at microfractures or preferential pore orientation, influencing permeability anisotropy.

Elastic simulations using the AF solver yielded a Young's Modulus of 16.88 GPa, while FFT-based simulations provided anisotropic stiffness tensors, indicating weak anisotropy. Thomsen's parameters confirmed near-isotropic behavior with minor directional variations.

These findings enhance understanding of coquina reservoirs, aiding in improved reservoir characterization. The integration of DRP and numerical simulations proved effective for characterizing complex porous systems, offering valuable tools for reservoir modeling. This research underscores the importance of advanced computational methods in addressing the challenges of heterogeneous carbonate reservoirs, contributing to more accurate predictions in reservoir characterization.