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Integrating seismic attributes with acoustic impedance assisted by self-organizing maps for reservoir characterization in the santos basin pre-salt

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Introduction

Reservoir characterization of pre-salt carbonates in the Santos Basin presents significant challenges due to their complex depositional history, structural compartmentalization, and the influence of hydrothermal processes (Vital et al., 2023; Lima & De Ros, 2019). The Barra Velha Formation, the primary reservoir unit in this setting, comprises lacustrine carbonates with low acoustic contrast between facies, which limits the effectiveness of traditional seismic interpretation methods (Chopra & Marfurt, 2007; Wright & Barnett, 2017). This complexity demands quantitative techniques capable of enhancing seismic resolution and capturing subtle geological heterogeneities.Among the depositional models proposed for this formation, Gomes et al. (2020) identified two main facies groups with distinct petrophysical characteristics: mud-poor facies, typically found on paleo-highs and associated with good reservoir quality, and mud-rich facies, more common in deeper zones and linked to lower porosity and permeability. Differentiating these facies in the seismic domain requires a multivariate and data-driven approach.In this context, the present study applies a workflow that integrates deterministic seismic inversion with Self-Organizing Maps (SOM), aiming to classify seismic facies in an unsupervised manner and to identify patterns that can be correlated with petrophysical data. By combining seismic attributes and well information, the methodology seeks to improve geological characterization and support the construction of more accurate reservoir models in complex pre-salt carbonate settings.

Method

To generate a P-impedance volume, a deterministic seismic inversion was performed. The low-frequency model used in this process was built from impedance logs derived from well data and propagated along a stratigraphic framework based on a Relative Geological Time (RGT) model. The resulting P-impedance volume, along with seismic amplitude and local dip attributes, was standardized and used as input for unsupervised facies classification using Self-Organizing Maps (SOM). This machine learning technique identifies natural clusters in multidimensional data without the need for predefined labels. Twelve initial SOM classes were generated and subsequently analyzed and grouped into four seismic facies based on their relationship with porosity and permeability logs. The volumetric distribution and petrophysical characteristics of these facies were then interpreted within a geological context.

Results and Conclusions

The clustering results revealed that one facies (SF1) consistently exhibits high reservoir quality and is predominantly located within the mound domain, aligning with the mud-poor facies described by Gomes et al. (2020), typically associated with shallow-water, high-energy environments. In contrast, facies with lower porosity and permeability (SF4) are more abundant in low-lying stratigraphic domains and are interpreted as mud-rich facies, related to deeper, lower-energy settings, also according to Gomes's classification. The acoustic impedance attribute played a pivotal role in capturing petrophysical contrasts and enhancing the resolution of facies boundaries. This workflow offers a fast and reliable approach to delineate reservoir-quality zones in complex pre-salt carbonates. Future improvements could include the integration of well data from a broader range of structural domains to reduce spatial bias and improve model robustness. Additionally, applying stochastic inversion and incorporating further seismic attributes may enhance the discrimination of reservoir properties and support more refined flow unit modeling.