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Feasibility Study of Bayesian Facies Classification to Guide Seismic Inversion in the Albacora Leste Turbidite Reservoir, Campos Basin

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Abstract Summary

This study focused on enhancing the facies characterization of a heterogeneous and complex turbidite reservoir, marked by thin intervals and interlaminated lithologies, from the post-salt section of the Albacora Leste Field, Campos Basin. To achieve this goal, a feasibility study and a comparison between Bayesian classification methodologies using seismic attributes were applied. The reliability in predicted sandstone facies reached 80.3% in one of the approaches, while the total accuracy was 76% across the reservoir interval. Interlaminated facies (heterolithic) exhibited complex petroelastic behavior, making their discretization in relation to the other facies not so simple. Therefore, the feasibility study and multi-attribute Bayesian classification proved fundamental in differentiating the oil sand electrofacies from non-reservoir facies in the AB-140 reservoir.

Introduction

The Albacora Leste Field, located in deep waters, stands out as one of the main turbidite systems contributing to oil and gas production in the post-salt section of the Campos Basin. Its reservoirs are composed of Oligo-Miocene sandstones from the Carapebus Formation, which exhibit excellent permoporous characteristics (Bruhn et al., 2003). However, the seismic characterization of this field remains challenging due to the presence of low acoustic impedance shales and interlaminated sandstone–shale facies (heterolith), whose thin layering compromises vertical seismic resolution within the reservoir intervals. This lithological complexity, combined with structural and fluid compartmentalization, makes seismic mapping and differentiation between reservoir facies and low-quality units difficult, directly impacting the seismic study of the field (Lemos et al., 2006).

In this context, rock physics has become a fundamental tool for reservoir characterization, as it aims to understand how geological aspects of reservoir zones influence the elastic behavior of the rocks, impacting decision-making for seismic inversion. Feasibility studies based on seismic attributes, such as impedances, are essential for establishing relationships between petrophysical and elastic properties, as well as contributing to the process of upscaling data for modeling reservoir properties (Mavko et al. 2020).

Bayesian classification is a supervised learning method that applies Bayes' Theorem to infer the probability of occurrence of a determined class and quantify the uncertainty of the prediction (Duda et al., 2001). As such, it is a statistical technique widely used in the classification of facies and in the process of upscaling from the well data scale to seismic scale (Avseth et al., 2005). In studies of heterogeneous and complex reservoirs, the use of elastic attributes has proven to be crucial for facies prediction, as highlighted by Fernandes & Lupinacci (2022).

Therefore, the aim of this study was to improve the differentiation between clay-rich facies, such as heterolith, and reservoir-quality facies, contributing to a more accurate geologic and geophysical characterization of complex turbidite systems that face this challenge.

Method and Theory

The delimitation of the AB-140 reservoir interval was based on stratigraphic markers previously provided for the study area. Well log data from four wells were utilized and subjected to a quality control process, which included the removal of noise and spike corrections. Electrofacies were classified following the methodology proposed by Martins et al. (2023), resulting in four categories: shale, heterolith, oil sand, and marl.

As part of the feasibility analysis, probability density functions (PDFs) and histograms of acoustic impedance (IP) and VP/VS ratio were generated to evaluate the petroelastic behavior of each electrofacies. The analysis was first performed using a univariate approach based solely on IP values. Subsequently, a bivariate (2D) analysis was conducted using crossplots of VP/VS versus IP, enabling a more robust assessment of the data distribution and class separability.

In the Bayesian classification stage, target classes, likelihood functions, and prior probabilities were defined. Prior probabilities were derived from the relative frequency of each electrofacies within the analyzed wells, with the following proportions assigned: 30% for shale, heterolith, and oil sand, and 10% for marl. This approach integrates prior geological knowledge into the classification process, enhancing the geological realism of the predictive model (Teixeira et al., 2017).

Thus, this study aimed to evaluate and compare the performance of 1D and 2D Bayesian classification techniques to improve the discrimination between reservoir and non-reservoir facies. The comparative analysis highlighted the advantages of incorporating multiple seismic attributes, reinforcing the effectiveness of multi-attribute Bayesian classification in facies prediction and in reducing interpretation uncertainties.

Results

The feasibility analysis revealed distinct petroelastic trends among the electrofacies when integrating acoustic impedance (IP) and VP/VS ratio (Figure 1). Shales and marls showed overlapping properties due to their clay-rich composition, while oil sands were distinguishable by lower impedance and VP/VS values, indicating better reservoir quality. Heteroliths presented intermediate behavior with significant overlap, underscoring the challenge of their classification using single attributes.

The 1D Bayesian classification resulted in 58% overall accuracy, with considerable confusion among shale,heterolith, and oil sand. The 2D classification, combining IP and VP/VS, improved accuracy to 76%, notably enhancing the identification of oil sands and shales (Figure 1). Although heterolith predictions declined slightly, the multi-attribute approach proved more effective for distinguishing reservoir from non-reservoir facies.

These improvements are also evident in the classification results for wells 9-ABL-3B and 9-ABL-9D (Figure 2), where the 2D method yielded better alignment with the reference facies log, particularly in intervals dominated by complex lithologies.

Conclusions

The Bayesian classification using both acoustic impedance and VP/VS ratio was more effective in predicting reservoir facies (80.3%) compared to the 1D approach (66.8%). This multi-attribute method enhanced the identification of reservoir-quality zones and improved the discrimination of clay-rich facies, particularly heteroliths. Overall, the feasibility study and 2D Bayesian analysis provided important insights into the influence of lithological variability on elastic responses, while also reducing uncertainties in facies prediction. Based on these results, the application of elastic inversion is recommended to further refine the seismic characterization and improve reservoir modeling of the AB-140 turbidite interval in the Albacora Leste Field.

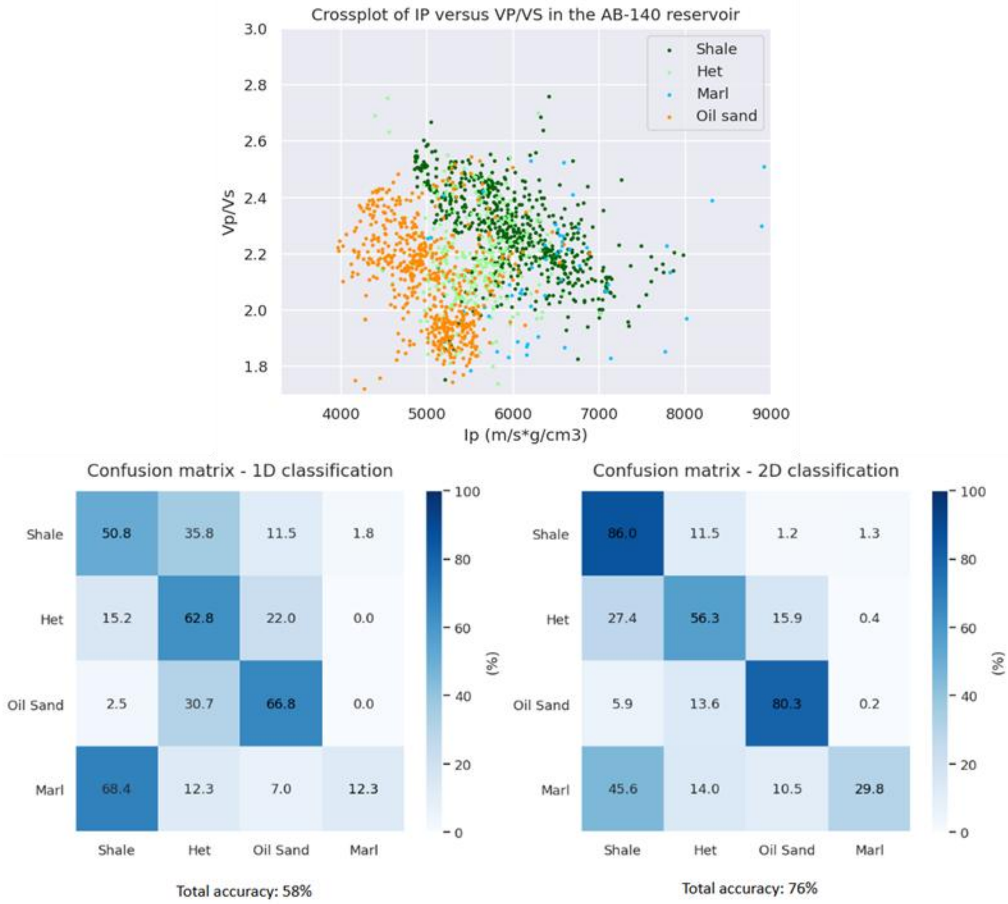

Figure 1: Top: Crossplot of acoustic impedance (IP) versus VP/VS ratio for each electrofacies within the reservoir interval. Bottom: Confusion matrices for the 1D and 2D Bayesian classifications are shown, along with their respective overall accuracy values.

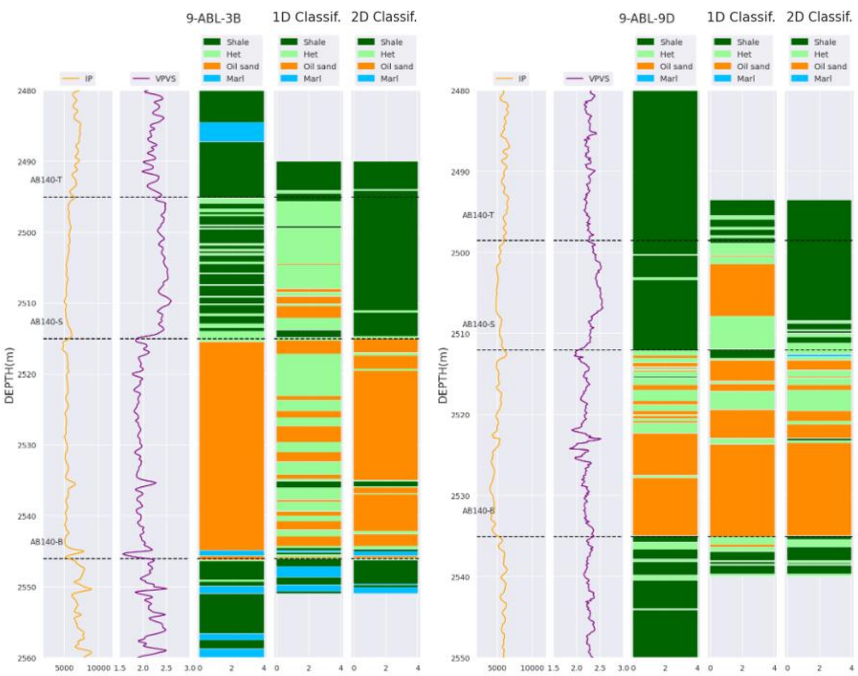

Figure 2: Log Plots with the results of the 1D and 2D Bayesian classification and the comparison with the interpreted facies log (track 3) for each well. Left: results for well 9-ABL-3B. Right: results for well 9-ABL-9D.

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