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Unveiling Structural and Stratigraphic Features of the Barra Velha Carbonates Using Seismic Attribute Analyses

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Abstract Summary

We use seismic attributes to reveal structural and stratigraphic features in the highly heterogeneous carbonate reservoir of the Barra Velha Formation (BVE) in the Santos basin, combining spectral decomposition, Grey Level Co-occurrence Matrix (GLCM) entropy and energy, coherence, curvature, and multispectral coherence volumes calculated over a post-stack seismic cube of 285 km^2 and displayed over surfaces corresponding to the Upper, Middle and Lower BVE. Preliminary results show that spectral decomposition is useful in identifying the seismic facies previously reported in the literature (Lagoon, External Mound, Mound, Clinoform, and Wedge) and highlighting the geometry of the prolific eastern margin area, while combined textural and discontinuity attributes enhance the structural domains and faults. Illumination differences, seismic resolution, and the presence of coherent noise in the seismic volume are the main factors that challenge the application of this workflow.

Introduction

Understanding the key structural and stratigraphic elements of any hydrocarbon-bearing reservoir is essential for geologic modeling, particularly the distribution of facies in the area. Carbonate reservoirs, however, are more heterogeneous and complex than siliciclastic reservoirs, since tectonic, sedimentation, water level variations, and climatic processes control carbonate deposition, growth and facies distribution. In addition, carbonates generally have lower vertical and lateral resolutions than siliciclastics, and a higher presence of interbedded multiples when packages of different carbonate rocks are in succession (Chopra and Marfurt, 2007).

In modern interpretation, seismic attributes have proven to be an effective approach for structural and stratigraphic reservoir characterization, detecting features below the resolution of conventional seismic data, especially in areas where little to no well logs are available (Chopra and Marfurt, 2007). For that reason, we propose a workflow using spectral, texture and discontinuity post-stack seismic attributes in a 285 km^2 area on the Brazilian pre-salt reservoir of the Aptian Barra Velha Formation in the Santos Basin, composed of a set of highly heterogeneous naturally fractured carbonate rocks, whose main facies correspond to fascicular calcite crusts (shrubstones) intercalated with grainstones and rudstones, and layers rich in magnesian silicates containing calcite spherulites (Wright, 2022).

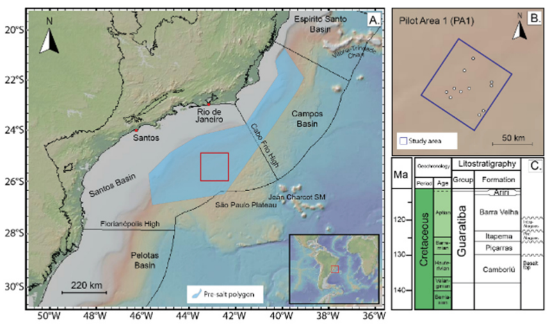

Figure 1: A. Approximate location of the study area (red square) within the pre-salt polygon in the Santos basin, offshore Brazil (modified from Silva Adriano et al., 2022), B. Seismic data polygon showing available wells with logs, and C. Stratigraphic chart of the Santos Basin. (modified from Moreira et al., 2007).

Methods and Theory

This workflow combines seismic attributes such as spectral decomposition calculated using the Continuous Wavelet Transform (CWT) method, Grey Level Co-occurrence Matrix (GLCM) entropy and energy, coherence, curvature, and multispectral coherence (coherence calculated over iso-frequency cubes) over a conditioned PSDM volume, to accentuate the architectural and structural elements in the study area. Interpretation and analyses were carried out using the RGB display of sets of three attributes, mainly over but not limited to surfaces corresponding to the Upper, Middle and Lower BVE. Finally, conclusions from the attribute analyses results were validated using well log data. Please note that due to the length limitation of this abstract, we are only showing examples of Middle BVE.

Results

Using spectral decomposition, we were able to identify previously interpreted seismic facies (Lagoon, External Mound, Mound, Clinoform, and Wedge) by Villacreses-Morales et al., 2023, except for the westernmost portion of the Clinoform facies, for which we propose an alternative boundary with the Wedge facies (Figure 2). We were also able to highlight the geometry of the eastern margin, composed by the External Mound and Mound facies, which will likely contribute to the improvement of the geologic model of the reservoir since the East has the best reservoirs in the field and a strong presence of reworked materials.

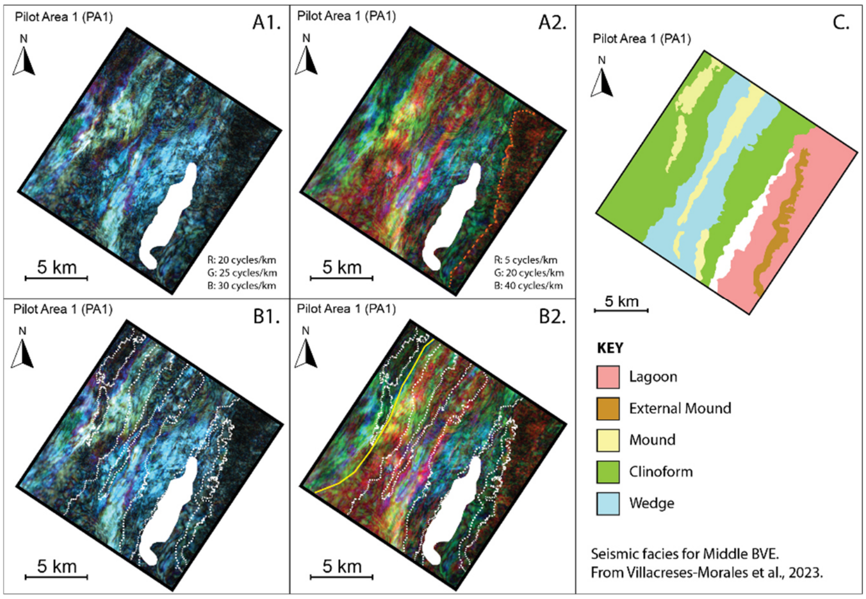

Figure 2: A1. RGB display of three spectral decomposition volumes (20, 25, and 30 cycles/km) over Middle BVE, A2. RGB display of three spectral decomposition volumes (5, 20 and 40 cycles/km) over Middle BVE. An orange dotted line is marking the eastern margin of the area. B1. RGB display of three spectral decomposition volumes (20, 25, and 30 cycles/km) over Middle BVE, with a white dotted line marking the facies limits from Villacreses-Morales et al., 2023, B2. RGB display of three spectral decomposition volumes (5, 20, and 40 cycles/km) over Middle BVE with a white dotted line marking the facies limits from Villacreses-Morales et al., 2023, and a yellow line indicating the proposed limit between the Clinoform and Wedge facies C. Seismic facies map at Middle BVE showing the five types defined by Villacreses-Morales et al. in 2023.

Textural attributes combined with the most positive and most negative curvature provided similar results compared to spectral decomposition on identifying seismic facies, while also better enhancing the structural domains on the eastern margin and showing a good correspondence with the interpreted faults defined by Mendes et al. (2024), as seen in Figure 3. Illumination differences, seismic resolution, and presence of coherent noise in the pre-salt section of the seismic volume are the main factors that challenge the application of this workflow. To address this, we have established low, middle, and high confidence zones in the seismic data and incorporated them into result evaluation, not shown in this abstract.

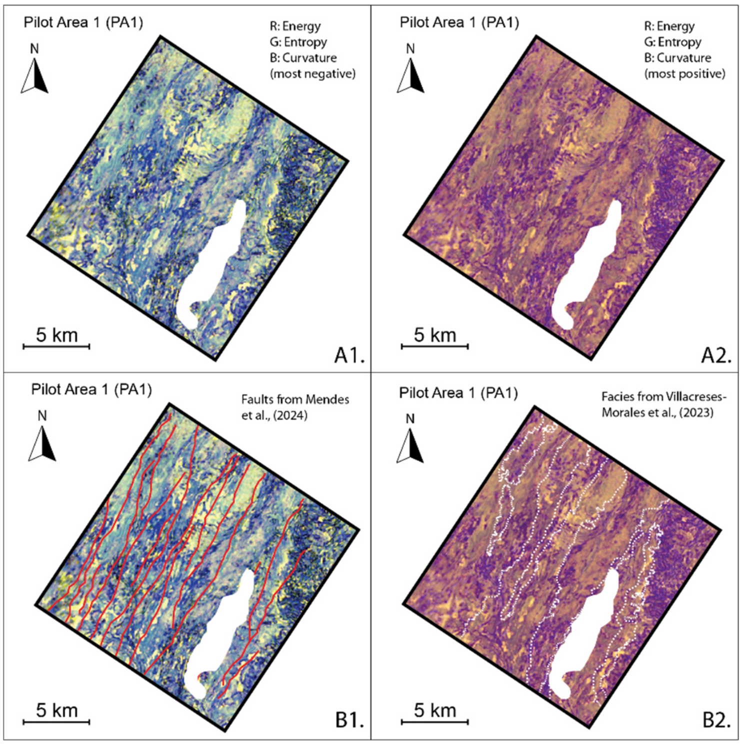

Figure 3: A1. RGB display of three spectral decomposition volumes (GLCM energy, GLCM entropy, and most negative curvature) over Middle BVE, A2. RGB display of three spectral decomposition volumes (GLCM energy, GLCM entropy, and most positive curvature) over Middle BVE, B1. RGB display of three spectral decomposition volumes (GLCM energy, GLCM entropy, and most negative curvature) over Middle BVE, with an overlay of faults (red) defined by Mendes et al., 2024, B2. RGB display of three spectral decomposition volumes (GLCM energy, GLCM entropy, and most positive curvature) over Middle BVE, with a white dotted line marking the facies limits from Villacreses-Morales et al., 2023.

Conclusions

The proposed seismic-attribute based workflow was able to identify and refine key seismic facies previously defined by Villacreses-Morales et al. in 2023, and highlight the structural domains and faults in the area defined by Mendes et al., 2024, by integrating spectral decomposition, textural, and discontinuity seismic attributes. The method has proven to be a time-efficient and cost-effective aid to conventional seismic and well log-based methods, allowing us to better characterize the complex carbonate reservoir of the Barra Velha Formation in the Santos Basin.

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