Mapping of Carbonate Mounds in the Brazilian Pre-Salt Zone

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Summary

Brazil began oil production from its pre-salt carbonate reservoirs in 2008. Recently, these reservoirs have reached an incredible output of 1.53 million barrels of oil equivalent per day (boed), representing more than half of the country's daily production. The rapid and high increase in oil production demonstrates how important these carbonate reservoirs are to Brazil. The Brazilian pre-salt oil fields are in an exploration and development phase, which requires an understanding of the complex geology of these areas. There are many challenges for characterizing carbonate rocks given their high spatial heterogeneity and complex pore systems. The main objective of this study was to propose a workflow for identifying and characterizing carbonate bodies, using a combination of structural attributes and the hybrid spectral decomposition method on these potential targets in the exploration of hydrocarbons.

Introduction

Carbonate mounds are potential oil-producing systems in many fields. Identifying and characterizing carbonate mounds in the Brazilian Pre-Salt, below complex and thick evaporite deposits, are considerable challenges for geoscientists. One of the major problems is seismic illumination of subsalt layers. Carbonate reservoirs in these areas are difficult to identify and delineate using seismic data because of their complex pattern of facies and the absence of impedance contrast between the reservoir and the sealing facies (Zheng, 2007). Seismic attenuation can greatly affect the quality of the seismic signal at considerable depths because of cumulative effects during down-going and up-going wave-field propagation (Lupinacci and Oliveira, 2015), making data preconditioning crucial (Lupinacci et al., 2017).

According to Chopra and Marfurt (2007), a seismic attribute is any measure of the seismic data that helps to visually enhance or quantify features of interest. Seismic attributes are important tool used for reservoir characterization. However, selection of seismic attributes should be made with caution so as not to propagate false interpretations. Carbonate mounds are complex sedimentary bodies that can be characterized by a combination of seismic patterns. Generally, their seismic facies are associated with chaotic, subparallel, wavy and concave seismic patterns (Carrillat, 2002). Seismic multi-attributes analysis can contribute to identifying these patterns.

Coherence attributes that compare neighboring seismic traces based on waveforms using cross-correlation, semblance, and eigen structure measures along the dip and azimuth of seismic reflectors have been developed (Bahorich and Farmer, 1995; Marfurt et al., 1998; Marfurt et al., 1999; Gerztenkorn and Marfurt, 1999). In recent years, coherence attributes have been applied to the margins of the Atlantic Basin in order to obtain accurate imaging profiles of the fault patterns infor hydrocarbon reservoirs that are difficult to identify from seismic reflectivity data.

The curvature attribute is a two-dimensional property that describes how bent a curve is at a particular point along its length (Roberts, 2001), focusing more on changes in shape rather than amplitude. Thus, this attribute is not affected by variation of amplitude in relation to fluids nor changes in lithology, so it is a good identifier of faults, as well as anticline and syncline structures (Pascal, 2008). However, the curvature attribute is sensitive to noise. Curvature attributes can increase confidence in the coherence results from geological analyses.

Spectral decomposition is another widely-used attribute. In seismic data, it can represent the seismic trace in a frequency domain or in sub-bands of frequencies. It can identify subtle thickness variations and discontinuities, as well as also accurately and quantitatively predict bedding thicknesses (e.g. Partyka, 1999). Low-frequency shadow is also used as a hydrocarbon indicator when applying the spectral decomposition attribute in hydrocarbon detection studies (Sun et al., 2002; Wang, 2007).

Additionally, a hybrid spectral decomposition attribute basically uses the result of spectral decomposition and selects the most important frequency bandwidth, which may be related to reservoir facies. Then, a specific amplitude range that represents a reservoir anomaly can be isolated.

Here, we propose a workflow for identifying and extracting mound geobodies in carbonate reservoirs. Our workflow uses the coherence and dip curvature structural attributes, combined with hybrid spectral decomposition. We successfully apply this workflow to reduce uncertainty in a static model of the Brazilian Pre-Salt reservoirs.

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Methodology and Results

High-resolution seismic data enable visualization and quantitative analysis of geometry, orientation, and spatial distribution of carbonate mounds (Ruf, 2012). Identification of geometric features, as well as mounds, is a considerable challenge in the Brazilian Pre-Salt formations due to difficulties in imaging seismic facies below large salt structures. Mapping of carbonate mounds would improve the ability to predict possible areas for hydrocarbon exploration.

The workflow we used for characterization of carbonate mounds is shown in Figure 1. In this workflow, the seismic data is preconditioned to optimize the attribute calculations, to improve the signal/noise ratio, and to increase vertical resolution. To do this, Structure Oriented Filtering (SOF) is used on the Reverse Time Migration (RTM) seismic volume to reduce noise and to improve the continuity, termination and geometry of events, which allows better definition of the reservoir architecture. We then calculated the Dip Curvature Attributes. Curvatures attributes are very susceptible to noise, which is why we calculated them after SOF. Spectral decomposition and hybrid spectral decomposition parameters were also obtained after applying SOF to maintain the original amplitude proportionality and thereby preserve the reservoir anomalies.

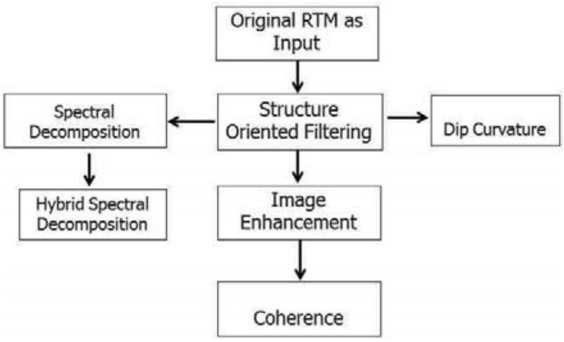

Figure 1: Workflow for preconditioning seismic data prior to characterization of carbonate mounds.

Calculation and analysis of the hybrid spectral decomposition attribute can be divided into two stages: (Stage 1) amplitude and frequency analysis, and (Stage 2) isolation of anomalies that can be associated with mounds.

(Stage 1) Amplitude and frequency analysis. The following steps were applied to the reservoir interval (with well logs used as a quality control):

1. Calculation of the dominant frequency;
2. Identification of the frequency that best characterized the anomaly of interest;
3. Calculation of the RMS amplitude;
4. Identification of the amplitude anomaly.

(Stage 2) Isolation of anomalies that can be associated with mounds:

1. Application of a Short Window Fourier Transformation approach using a Hanning filter.
2. Selection of the frequency of interest based on the Stage 1 analysis described above. In this work, we used 8 Hz as a central frequency;
3. Calculation of the Envelope attribute;
4. Isolation of the amplitudes of anomalies associated with carbonate mounds.

We obtained a hybrid spectral decomposition following Stage 2. Figure 2 shows the spectral decomposition and hybrid spectral decomposition on the structural map of the top of the reservoir.

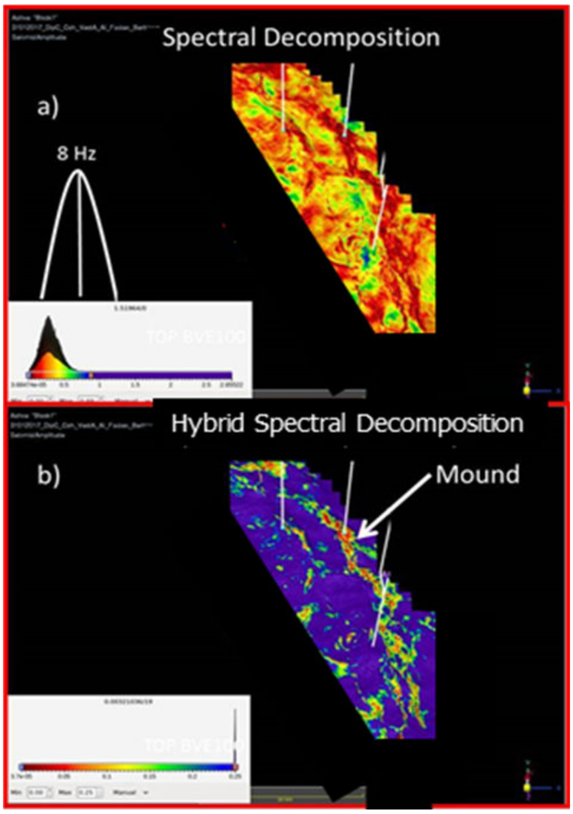

Figure 2: a) Spectral decomposition with a central frequency of 8 Hz. b) Result of our hybrid spectral decomposition, isolating the carbonate mounds.

In our workflow, spectral enhancement (or image enhancement) was applied before calculating the coherence attribute. The main objective of image enhancement is to improve seismic resolution by increasing the frequency bandwidth. This process does not create new frequencies; it only enhances the contributions of the weak frequencies that already exist in the seismic data. The coherence and dip curvature attributes calculated on the structural map of the top of the reservoir are shown in Figure 3.

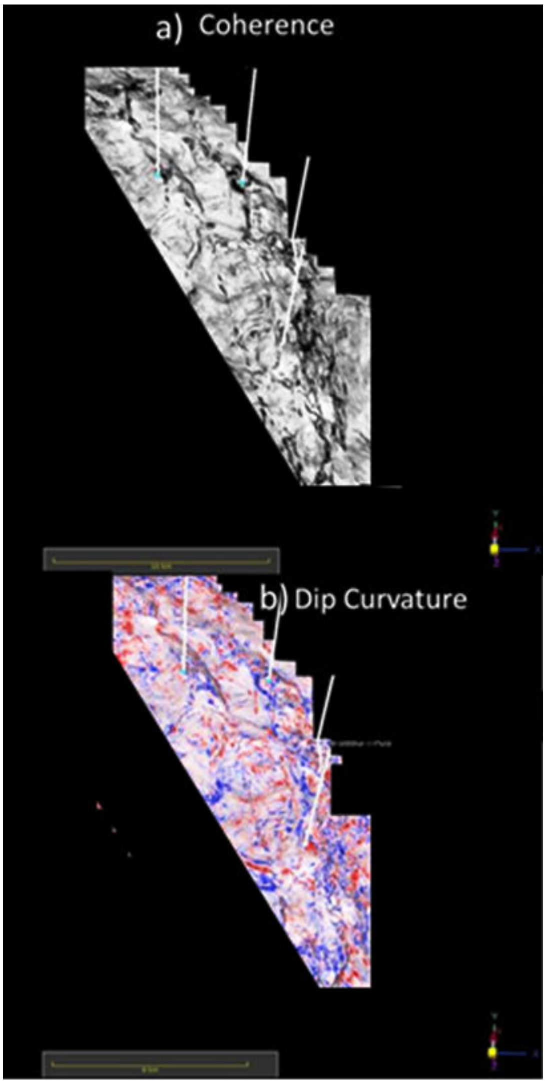

Figure 3: Coherence (a) and dip curvature attributes (b) calculated on the structural map of the top of the reservoir.

We then grouped the seismic facies for several regions of the reservoirs based on the seismic patterns, with the well logs used as a quality control parameter. We could then classify the seismic facies using the coherence, dip curvature and hybrid spectral decomposition attributes as input data for an unsupervised neural network algorithm, this classification is based entirely on the internal structure of the seismic data, and the resulting facies map is indicative of the reservoir heterogeneity (e.g., channel limits and orientation, or high- and low-porosity regions), Saggaf (1999). We also applied principal component analysis (PCA) to identify lateral variation in the carbonate reservoir.

Finally, after classification of the seismic facies, it was possible to identify and isolate the carbonate mounds. In Figure 4, the features that represent these mounds are clearly visible. In order to optimize the extraction process, automatic detection is limited to the top and base of the reservoir. Figure 5 shows the geobody of the carbonate mounds.

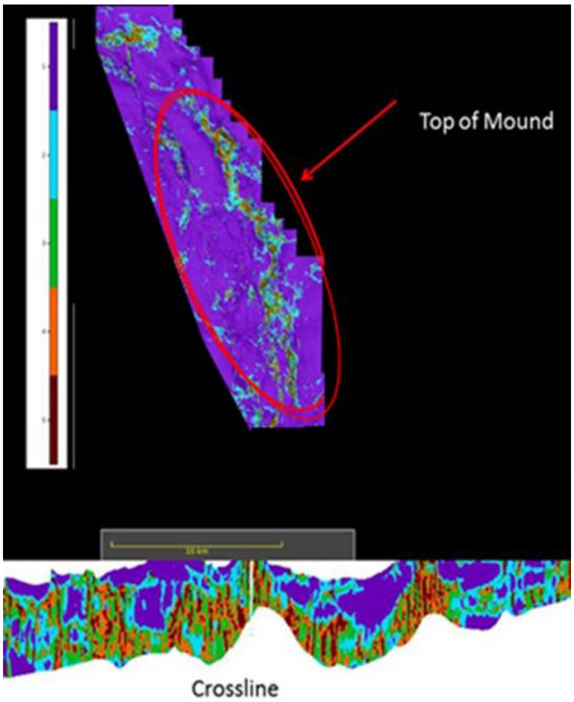

Figure 4: Structural map of the top of the reservoir, highlighting the carbonate mounds.

Conclusions

A combination of structural attributes and hybrid spectral decomposition successfully characterized carbonate reservoirs. Our results are corroborated by well logs, demonstrating the efficiency of this method in the complex environment of the Brazilian Pre-Salt. Our workflow allowed extraction of the geobody of the carbonate mounds and mitigated some uncertainties from the complex geology of the pre-salt zone.

Acknowledgments

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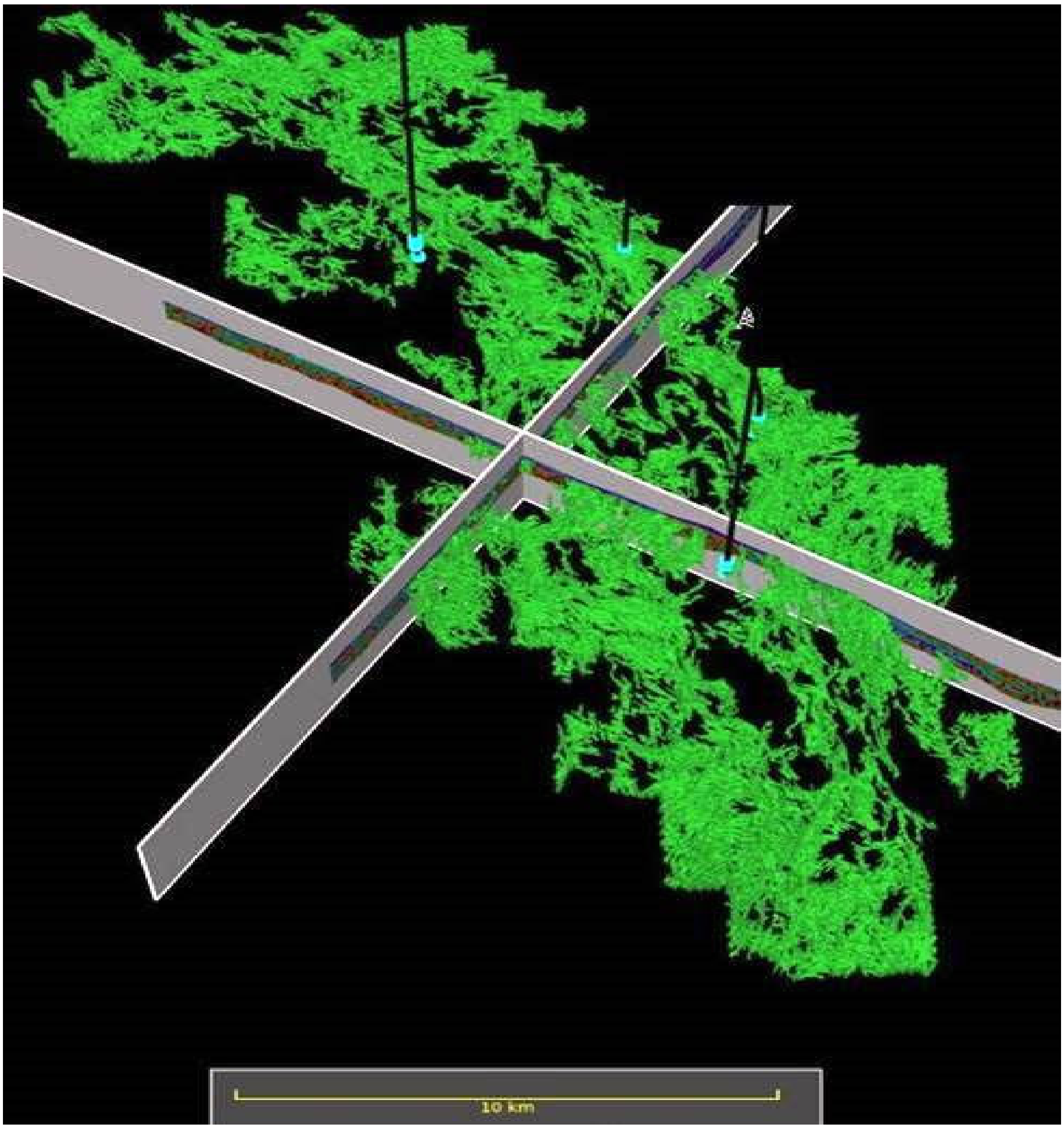

Figure 5: Geobody of carbonate mounds.

EDITED REFERENCES

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