Advanced Seismic Attribute Techniques for Evaluating CO_2 Sequestration in Depleted Onshore Gas Fields

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Abstract

The Parnaíba Basin, situated in northeastern Brazil, is recognized as a prolific onshore gas production region due to its geological evolution, which has resulted in an atypical petroleum system. Due to its unique geological characteristics and the potential implications of magmatic activity for energy resources, this basin is strategically investigated for Carbon Capture and Storage (CCS) initiatives. Seismic methods have been extensively employed for various geosequestration-related studies, including site characterization and monitoring. This study aims to analyze the seismic geometry of igneous intrusions and sedimentary records utilizing seismic attributes. Integrating seismic cube data and well information enabled a comprehensive assessment, facilitating detailed descriptions of seismic facies and structural features. The results produced a 3D seismic reservoir characterization that accurately represents the stratigraphic variability of subsurface properties, thus mitigating subsurface uncertainty within the study area.

Introduction

Global hydrocarbon reserves are estimated to sustain production for several decades. However, evidence of climate change, driven by greenhouse gas emissions, is compelling. Consequently, many countries are promoting Carbon Capture and Storage (CCS). Depleted oil and gas reservoirs are prime candidates for geological CO2 storage due to extensive prior studies and rich data availability on these fields and basins (Agartan et al., 2018).

In Brazil, the unique geological context of the Parnaíba Basin makes its gas fields prime candidates for carbon capture and storage (CCS) studies. Understanding the geometry and emplacement of igneous rocks is crucial for deciphering sedimentary basin evolution, as these factors influence source rock maturation, migration pathways, reservoir formation, and the development of anticlinal traps (Pongwa Pee et al., 2020).

Compared to surrounding host rocks, the high-impedance nature of igneous rocks allows amplitude anomaly-based attributes to effectively identify igneous bodies within siliciclastic sequences. Even though these magmatic features of Parnaíba Basin are well recognized, a characterization based on 3D seismic interpretation is scarce in this Brazilian Basin. To map these igneous bodies, we interpreted 3D PSDM seismic data with digital well logs of the Gavião Real Field. This comprehensive characterization aims to accurately represent seismic facies variations and, most importantly, assess potential risks and seal integrity, thereby evaluating the CO_2 storage potential and predicting long-term CO_2 plume behavior.

Data and Methods

First, we defined the surfaces of the sill, as well as the reservoir (Fm. Poti). The seismic volumes used were depth-migrated and constitute a merge of the 0313_3D Gavião_Real and 0303_3D CAPINZAL DO NORTE projects. Then, using the Attribute-Assisted Seismic Processing & Interpretation (AASPI) software, we applied a seismic data preconditioning workflow to optimize the signal-to-noise ratio, improving the seismic resolution of the entire cube, with special emphasis on the reservoir zone.

The application of coherence attributes, oriented by dip and azimuth, represented an effective approach to mitigate the impact of anomalies induced by the structural complexity of the subsurface. Considering that the integrity of the seal is crucial for the feasibility of gas storage in this project, a fault probability attribute was generated with the specific objective of evaluating the presence of potential zones of weakness at the top of the sill. The algorithm for generating this attribute uses a combination of fault prediction with a convolutional neural network and a skeletonization process.

Additionally, volumes of seismic attributes such as RMS amplitude and total energy were generated to provide a comprehensive view of the characteristics present in the seismic data. The generated attribute volumes were integrated with well information provided by the National Agency of Petroleum, Natural Gas and Biofuels (ANP) and ENEVA. The seismic and well information capture the spatial distribution of facies and petrophysical properties.

Results

Figure 1 shows the basalt top surface along with the fault probability attribute. This attribute delineates the boundaries of the sills and their internal discontinuities.

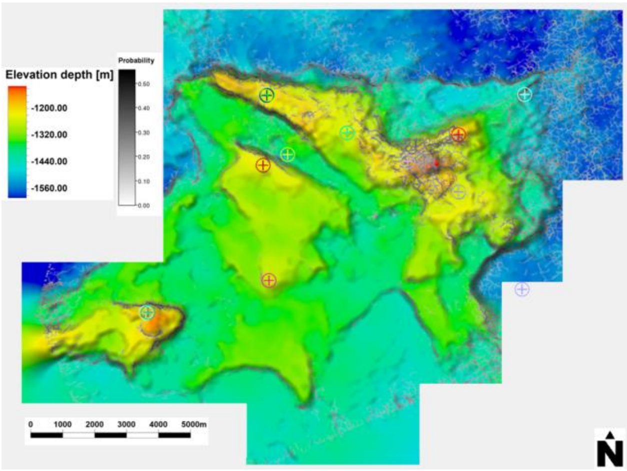

Figure 1 – Merge of the basalt top surface with the fault probability attribute (skeletonization process). The black lines indicate the fault probability results.

Figures 2 and 3 show the relationship between seismic amplitude and fault probability. The regions indicated by black dashed circles reveal discontinuities in the main sill of the field, cutting only the upper and lower parts of the sill. However, in Inline 641 (Figure 4), the sill does not have discontinuities, showing only a subtle sill jump.

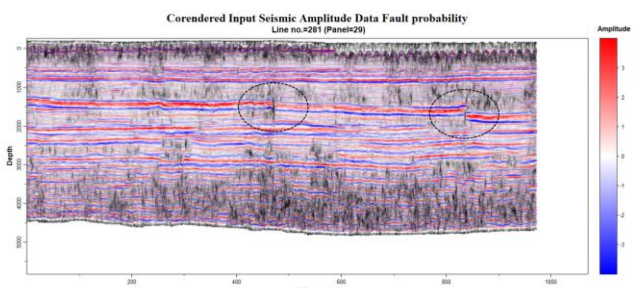

Figure 2 - Relationship between seismic amplitude and fault probability. Note the discontinuities in the regions indicated by black dashed circles.

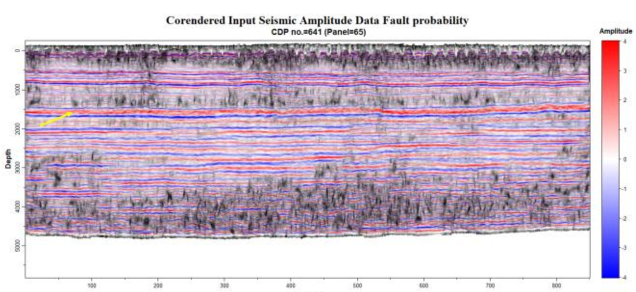

Figure 3 - Relationship between seismic amplitude and fault probability. Note the integrity of the sill reflector indicated by the yellow arrow.

The following figures present the RMS amplitude and total energy attributes on the mapped surface, allowing for the delineation of the geomorphology of the sill and its discontinuities. These attributes offer insights into the strong amplitude of the sill in the southern sector of the Gavião Real field, as well as in the northeast sector. (Figures 4 and 5).

Figures 6 and 7 present lithotype differences at greater depths. RMS amplitude is also in the interpretation of the Poti Formation by considering the continuity of the reflector and the amplitude value. The total energy attribute refers to the sum of the squared amplitude values within the analysis window, which is suitable for studying changes in lithological trends.

In the Poti Formation, the reservoir zone, strong anomalies of RMS amplitude and total energy exhibit similarities, following an NW-SE trend along the drilled wells.

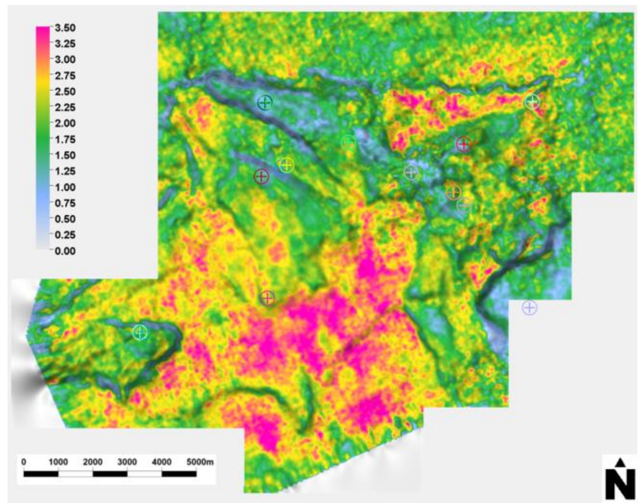

Figure 4 - RMS amplitude attribute on the sill top surface

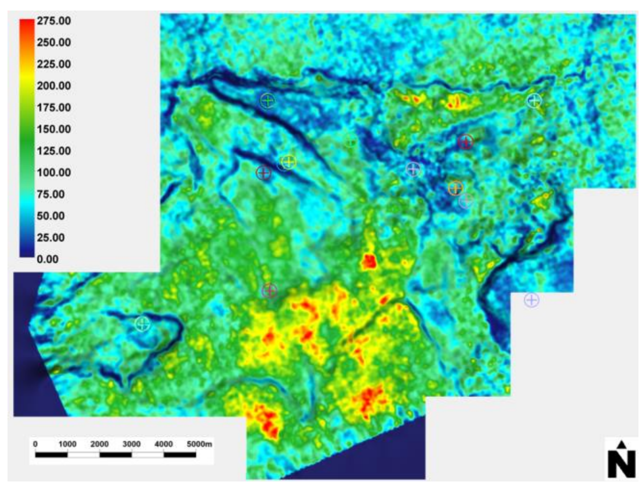

Figure 5. Total Energy attribute on the sill top surface

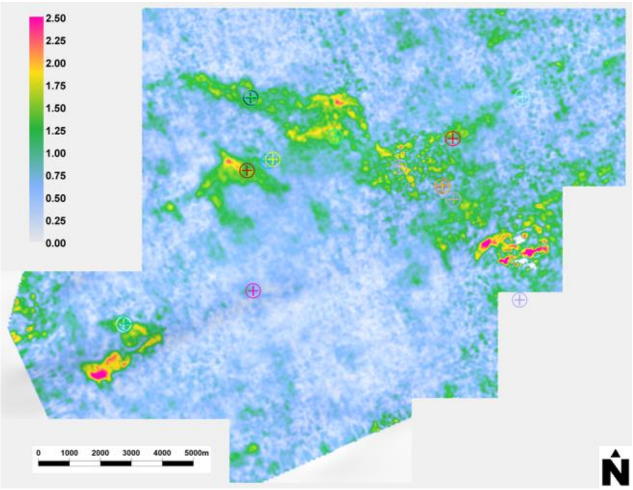

Figure 6. RMS amplitude in the reservoir zone of the Poti Formation.

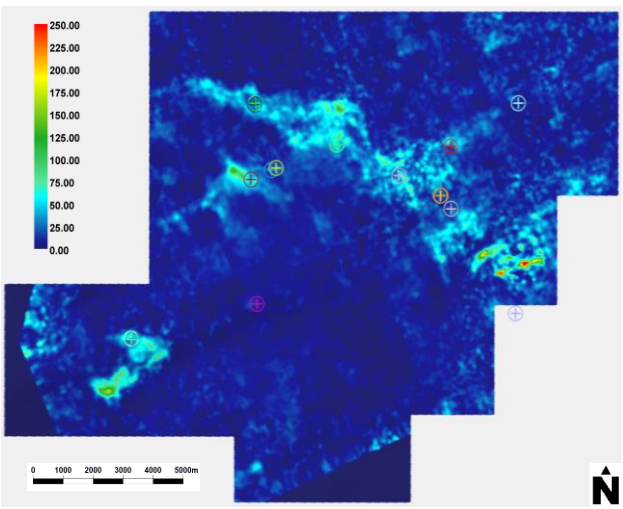

Figure 7. Total Energy attribute in the reservoir zone of the Poti Formation.

Discussion and Conclusions

The fault probability attribute revealed the geomorphology of the sill within the Gavião Real field, as well as its discontinuities. However, definitive assertions about the presence of faults in the sills cannot be made due to specific considerations related to their genesis. According to Aguiar (1971) and Trosdtorf Junior et al. (2014), two magmatic events occurred, generating variety in the geometry and geology of igneous bodies within sedimentary layers. Consequently, gas generation was facilitated by the high temperatures of the diabase sills, which, through jumps, formed structural highs that trapped the gas (Rodrigues, 1995). Thus, the internal discontinuities can be associated with sill jumps in regions of limb amalgamation (Miranda et al., 2018). Researchers are being conducted to better understand the seal integrity.

The RMS amplitude and total energy attributes demonstrate sensitivity to sandstones bodies; however, in this field, magmatic bodies are also highlighted. Integration with well data could support this interpretation, and petrophysical data are being integrated to better constrain porosity and permeability parameters.

The workflow applied in this study is expected to yield geologically sound results by bridging the gap between wells and reducing uncertainty in areas with limited well control. Compared to previous studies, this seismic-assisted evaluation produces 3D reservoir characterization that represents the stratigraphic variability of subsurface properties in greater detail, thereby further reducing subsurface uncertainty in the study area.

Acknowledgments

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