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Waveform Clustering Using Different Approaches of Dimensionality Reduction Algorithms Applied in Campos Basin

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Introduction

Traditional seismic interpretation is often based on attributes extracted from seismic traces, typically focusing on amplitude or reflector continuity. However, the complete seismic waveform comprises valuable information related to lithological and stratigraphic properties, offering a powerful tool for identifying complex geological features. This work proposes a methodology for analyzing seismic waveform clustering using unsupervised machine learning techniques, emphasizing the importance of dimensionality reduction and clustering of seismic patterns.

Method

Dimensionality reduction was performed using the t-Distributed Stochastic Neighbor Embedding (t-SNE) and Principal Component Analysis (PCA) algorithms, which project high-dimensional waveform data into a lower-dimensional space while preserving local and global relationships. Subsequently, the Self-Organizing Map (SOM) clustering algorithm was applied to classify the waveform patterns. The proposed methodology was initially tested on a synthetic seismic model generated by convolution with three different wavelets (Ricker, Ormsby, and Gabor), allowing for a direct comparison between the PCA and t-SNE projections and assessing robustness under varying noise levels. The methodology was then applied to real seismic data from the Campos Basin, using as reference the interpreted horizon corresponding to the top of the sandstone of the Carapebus Formation (TPA), located in the Marlim Field.

A waveform-based pseudocube was constructed around the TPA horizon for real-data analysis. Spatial cropping and preprocessing steps were implemented to enhance computational performance and ensure data quality. The clustering results revealed geological features consistent with the regional stratigraphic interpretation, such as channels, deltas, and listric normal faults. Clustering quality was quantitatively evaluated using the Rand Index, validating the methodology in the synthetic scenario and reinforcing its interpretive potential in real seismic data.

Conclusions

The results demonstrate that integrating waveform analysis with dimensionality reduction and unsupervised clustering techniques offers a robust and informative alternative to conventional seismic interpretation. Different approaches to waveform clustering were compared, where the t-SNE performed better in the synthetic scenario, compared with traditional waveform and PCA waveform. The proposed waveform clustering approaches enhanced the identification of geological heterogeneities along seismic horizons in an automated and data-driven manner.