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Deep Learning for Identifying Geological Faults in Deep Waters of the Ceará Basin, Brazilian Equatorial Margin

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Introduction

The Ceará Basin, located on Brazil's equatorial margin, has a complex tectonostratigraphic history of rifting and thermal subsidence. In its deepwater areas, normal and strike-slip fault systems control structural compartmentalization and hydrocarbon dynamics. Therefore, characterizing these faults is crucial for improving geological models and reducing exploration uncertainties. In the current context of computational geoscience, machine learning techniques—particularly Convolutional Neural Networks (CNNs)—are increasingly applied to seismic data interpretation. This study proposes an automated methodology for seismic fault interpretation in the Mundaú Sub-basin, central Ceará Basin, using CNNs trained on derived seismic attributes. This strategy aims to optimize interpretation time and enhance the accuracy of identifying and mapping relevant tectonic structures, thereby advancing the region's geological understanding and expanding its deepwater exploratory potential.

Method and/or Theory

The method employs 3D seismic data converted to VDS (Volume Data Storage) format and processed using discontinuity attributes, which form the basis for model training and implementation. To enable automated interpretation of geological faults, five seismic attributes were generated to enhance discontinuities and optimize their detection by the algorithm. The selected attributes include: (i) Antitracking, which suppresses noise and highlights linear features; (ii) Variance, used to emphasize abrupt variations in seismic reflector responses; (iii) RMS Amplitude, which identifies zones with higher reflection energy; (iv) Chaos, designed to map regions with chaotic patterns of structural disorganization; and (v) Structural Smoothing, which applies edge-preserving filters to maintain essential geometric features. To enhance model robustness, merge of the RMS Amplitude and Chaos attributes was performed, combining seismic energy information with discontinuity patterns. The training process employed the E-Net (Efficient Neural Network) architecture, selected for its computational efficiency and ability to balance accuracy and performance in segmentation tasks. This approach yielded optimized results, reducing computational costs while maintaining accuracy in the identification of geological structures.

Results and Conclusions

The results indicate a predominance of normal faults with a preferential NW-SE orientation, although faults with divergent dips were also identified. These structures predominantly exhibit subvertical geometries. Furthermore, faults extending to depths greater than 6 km and ascending to approximately 2 km were identified, representing structures of major significance for the tectonic evolution of the basin.The application of advanced computational techniques, such as automated interpretation using convolutional neurais networks (CNNs), has demonstrated significant potential to enhance structural characterization and reduce the subjectivity inherent in conventional seismic interpretation methods. This research contributes to the development of a more robust and detailed tectonostratigraphic model of the deep-water portions of the Mundaú Sub-basin, improving the understanding of structural compartmentalization and hydrocarbon migration controls. Moreover, it reinforces the importance of integrating geosciences and artificial intelligence as a promising approach for innovation in offshore exploration.