AI-ASSISTED STRUCTURAL INTERPRETATION OF COMPLEX FAULTING AND SALT ACROSS THE SHELF AND SLOPE OF THE CAMAMU SUB-BASIN, NORTHEASTERN BRAZIL

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Summary

The Camamu sub-basin in northeastern Brazil experienced oblique, northwest-to-southeast extension and complex rifting as the Atlantic Ocean opened from south to north in the Early Cretaceous. The 12,000 km^2 basin is flanked to the south by the Almada sub-basin and to the north by the offshore Jacuípe and onshore Recôncavo basins. It preserved pre-rift, syn-rift, and post-rift deposition, and has been mapped as the northern limit of Aptian salt (Davison, 1999). We mapped fault planes and salt bodies on the shelf and upper slope of the Camamu sub-basin by applying supervised deep learning and seismic interpretation methodologies to a 1,400 km^2 3D survey. Our interpretation workflow included: 1) labeling key geologic features to interactively train the AI neural network; 2) fully interpreting select inlines and crosslines, capturing the complexity of interpreted features; and 3) creating a final 3D model of inferred fault planes and salt bodies. Results suggest that shallow, post-rift normal faults dip offshore, are listric, and sole out along two sub-horizontal detachment zones. Deeper faults within syn-rift, pre-rift, and basement rock are also listric normal faults but sole out across a mid-crustal detachment at a depth of 6.5 seconds two-way time. Today, salt occurs as isolated pillows, welds, and small diapirs, but we infer that the original Aptian evaporite body was thicker following deposition and deflated through post-rift sediment loading, much like in the southern Almada sub-basin (Brandão et al., 2020).

Introduction

The Camamu sub-basin has been traditionally interpreted as the northern limit of Aptian evaporites. Though most workers mention small amounts of salt, they do not explore salt tectonics to a large extent (Davison, 1999; Blaich et al., 2010). Some researchers even discount the development of salt-related mini-basins within the Camamu (Scotchman and Chiossi, 2009).

AI-assisted interpretation methodologies were used in the present work to quickly interpret a 3D survey on the shelf and upper slope areas of the Camamu sub-basin (Figure 1). Both fault planes and salt bodies were interpreted to propose a post-rift history that began with a thick, Aptian evaporitic body that later deflated. This salt movement left behind multiple salt detachments and salt-withdrawal mini-basins.

Understanding salt tectonism and remnant salt bodies is significant for oil and gas exploration; presently, small subsalt gas accumulations have been discovered in the coastal area (Gonçalves et al., 2000). Determination of salt movement and abundance is timely and necessary for future hydrocarbon exploration efforts in the region, and in-depth study is required to successfully characterize these structures.

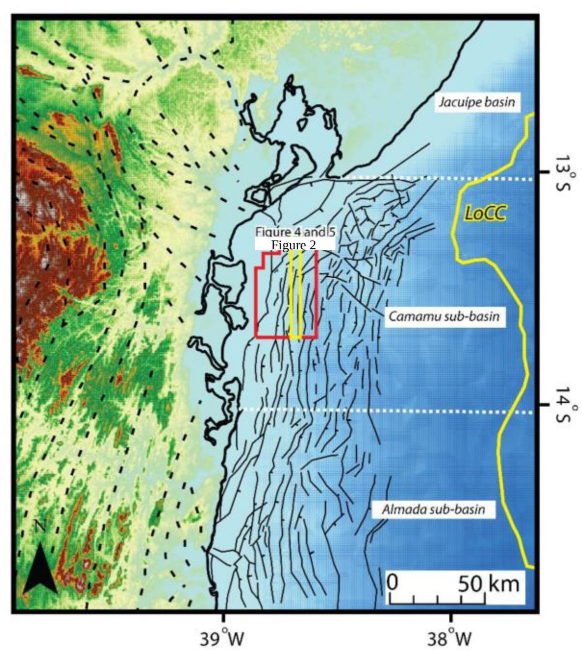

Figure 1: Map showing the distribution of subsurface data used for this chapter. 3D seismic survey (BCAM-40-BM-CAL-4) was provided by ANP and is shown in the red box located over the shelf and upper slope of the Camamu sub-basin. Strike seismic lines shown in Figure 2 are located in yellow and cross an area of northwest-southeast striking offshore basement faults (solid black lines; Ferreira, 2018) and onshore basement orogenic grain (dashed black lines).The topographic and bathymetric grids are from GEBCO (2021).

Supervised deep learning interpretation of the Camamu basin, offshore Brazil

Dataset and methods used within study

A 1,400 km^2 3D post-stack time-migrated survey shot by Petrobras in 2013 and made public in 2018 (Figure 1) that contains a grid of 1150 inlines and 1975 crosslines was interpreted. This dataset was kindly made available by the Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP). Supporting data included three different 2D surveys and 105 well logs in the area, 23 of which are within, and were tied to the 3D survey.

The following AI workflow was used in the interpretation of both fault planes and salt bodies (Figure 2):

- Initial inspection and selection of a representative seismic line
- Human interpretation and labeling of resolvable features
- Initialization of network training using Bluware algorithms to generate AI inferences
- Comparison of inferences to user labeling to improve interpretation. Training model reset; new line chosen

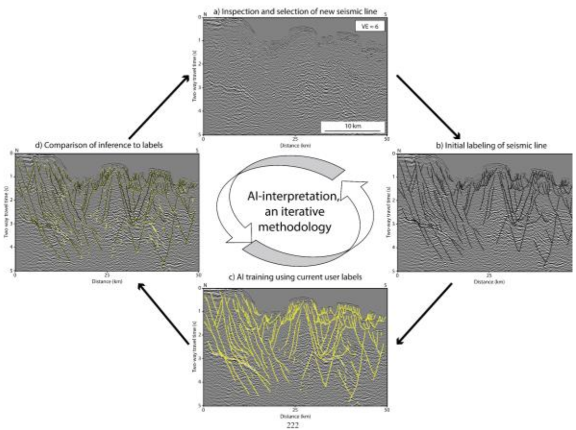

Figure 2: Summary of the iterative, artificial intelligence (AI)-based methodology used (seismic line shown is line 1743 from the ANP survey BCAM-40-BM-CAL-4 3D that is located on Figure 1). The four, repeated steps included: a) Initial inspection of the seismic to select and label lines that are representative of the structural diversity of the dataset used to train the AI model; b) Fault planes and salt bodies interpreted and labeled using InteractivAI software; c) AI neural network initiated and run until the model could approximate the user-interpreted labels. d) User-interpreted labels compared to the AI interpretations to see if there were any additional geologic features that needed to be labeled and updated. These four steps were repeated until the neural network was capable of successfully interpreting both the user-labeled lines and uninterpreted, random lines from the survey.

Results: Salt tectonics within the Camamu basin.

Salt bodies in the Camamu sub-basin are thin to absent under the shelf (Figure 3), while beneath the slope region isolated salt bodies increase in both frequency and size. These salt bodies thicken and become more numerous in a southwestwardly direction, which is consistent with the overall movement of salt as it evacuated from the shelf area and was displaced down the slope. The concentrations of faults and salt are sub-parallel to the shelf break and follow a curvilinear pattern that suggests linked deformation (Figure 3).

Dense 3D meshes of faults were interpreted under the shelfal and slope areas (Figure 3). In the present-day slope region, most are listric normal faults that dip seaward and detach along two distinct planes, likely forming as thick post-rift sag and passive margin sequences deposited and remobilized the underlying salt by differential loading.

Conclusions

This work shows that it is possible to use AI-assisted interpretation tools to interpret older, low signal/noise vintage 3D seismic across structurally complex environments, such as the deformed rifted-passive margin of northeastern Brazil. The high level of detail for the AI-assisted interpretation of salt and faults, which took several weeks, would not have been possible to manually map over a period of several months.

The results of our interpretation suggest that the near-shore Camamu basin once contained a much thicker and more extensive Aptian salt body than previously recognized.

Progressive loading of the salt body by coastal-derived clastic sediments led to the seaward and downslope evacuation of the salt in several pulses during the Cretaceous and Cenozoic. AI-assisted seismic interpretations enabled mapping of small and isolated salt bodies and post-rift listric normal faults that detach along two basinward-dipping detachments, one at the base of the Aptian salt and the other along a major Eocene unconformity.

These results change the present understanding of the distribution and original thickness of the Brazilian salt basin. Previously considered salt-poor and the northern limit of Aptian salt offshore Brazil, the Camamu salt basin was once considerably thicker and more extensive – but today has been largely evacuated.

Acknowledgements

We would like to acknowledge ANP for providing the 3D seismic data and Bluware for providing their Headwave and InteractivAI software used within this study.

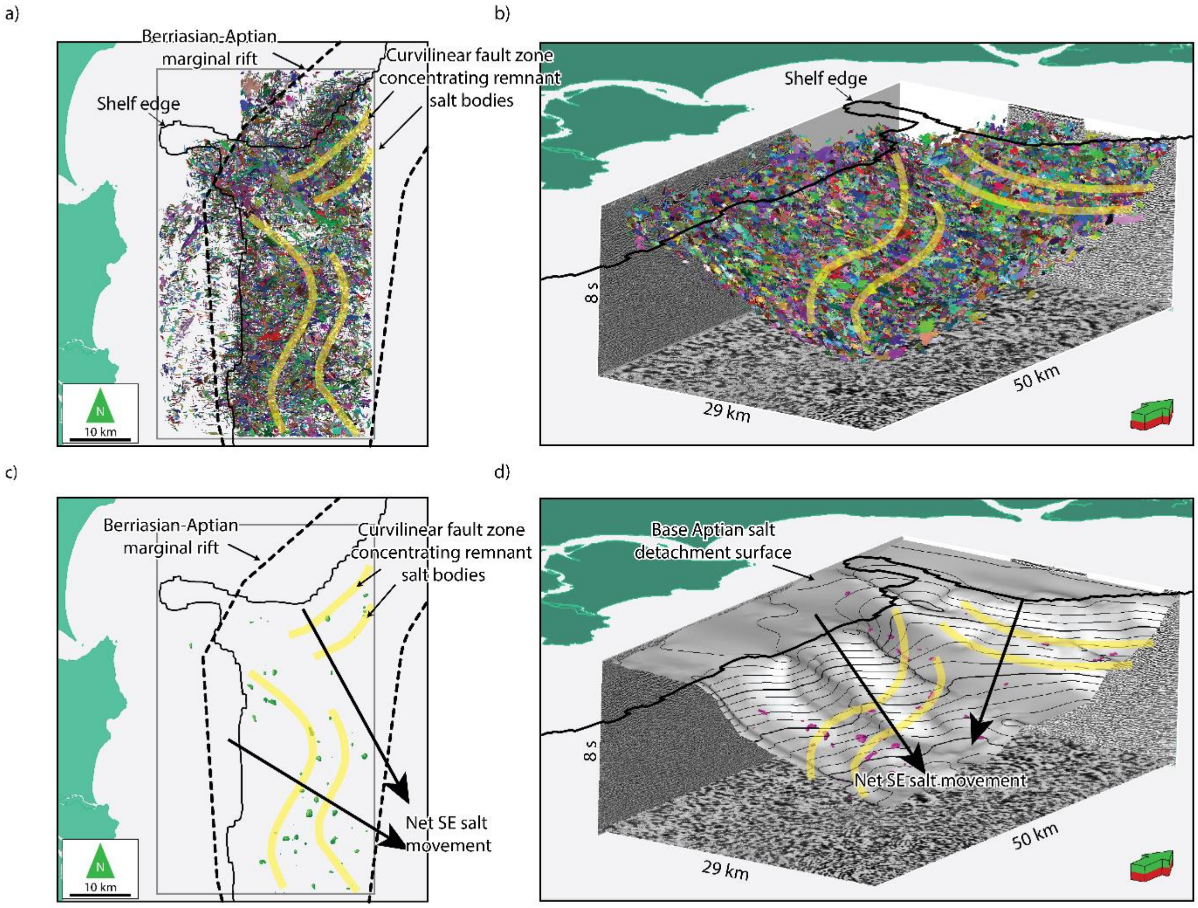

Figure 3: a) Map of all fault planes interpreted using the AI-based interpretation. Curvilinear trends in the light, yellow lines indicate concentrations of AI-mapped faults that are associated with the isolated salt bodies. The shelf edge is marked by the black line and the inferred edges of the Berriasian-Aptian marginal rift is shown by the black dashed line. b) Block diagram based on the 3D seismic cube showing the same map area; the curvilinear trends shown by the light, yellow lines are concentrations of AI-mapped faults that are associated with the isolated salt bodies. c) Map view of isolated salt bodies, in green, interpreted by the AI- based methodologies with the yellow lines marking concentrations of AI-mapped faults associated with those salt bodies, and the dotted lines showing the extent of the original salt basin concentrated in the sag above the marginal rift. The combined map patterns indicate that most of the salt has evacuated from beneath the shelf area in a southeastern direction and now underlies the upper slope. d) Block diagram based on the 3D seismic cube showing the dip on the base Aptian salt detachment, the isolated salt remnants in red, and the concentrations of AI-mapped faults shown as the yellow lines. The interpretation is that the salt has been evacuated from beneath the shelf and has now moved downslope and to the southwest along both a lower base Aptian salt detachment and a shallower Eocene detachment.

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