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Fracture network analysis using acoustic image logs in the Itapema and Barra Velha formations, Búzios Field, Santos Basin

Ana Carla Pinheiro (Federal Fluminense University - GIECAR), Isadora Dutra (Fluminense Federal University), Wagner Lupinacci (GIECAR), Ana Carolina Carius (Fluminense Federal University), Francisco Abrantes Junior (Universidade Federal Fluminense), Ricardo Jahnert (UFF)

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Abstract

This study focuses on well 3-BRSA-1195-RJS, located in the northern sector of the Búzios Field, with particular emphasis on the Barra Velha and Itapema formations. The objective is to analyze and classify natural fractures through the interpretation of acoustic images, nuclear magnetic resonance (NMR), and lithogeochemical logs, aiming to delineate fracture zone distribution and identify structural trends. In this well, orientation and dip angle measurements of natural fractures and breakouts were systematically acquired. Image log interpretation was crucial for delineating fracture zones, improving the understanding of the relationship between fracturing, porosity, and silica content, revealing a strong correlation between the silicification process and fracturing.

Introduction

The Santos Basin, located in the southeastern region of Brazil, is bounded to the north by the Cabo Frio High structure and to the south by the Florianopolis High structure (Moreira *et al*., 2007). Oil exploration in the basin began in the 1970s, but only in 2006, with the discovery of the pre-salt, the Santos Basin gained prominence and significantly transformed the Brazilian exploration sector (Freitas *et al*., 2019).

In the 1980s, image logs emerged as an innovation in geological data processing, utilizing high-resolution tools to capture images of the wellbore wall through physical properties such as electrical resistivity and acoustics (Zeng *et al*., 2021). These logs allow for the identification of textural features of rocks (Donselaar and Schmidt, 2005) and provide directional information, including sedimentary and structural elements (Lai *et al*., 2018). Furthermore, image logs are crucial for identifying facies and analyzing structures such as layers, fractures, faults, folds, and unconformities. In this context, this study focuses on analyzing and classifying natural fractures interpreted from acoustic image logs, with the objective of mapping the spatial distribution of fracture zones and identifying prevailing structural trends in pre-salt successions.

Method

This study utilized data from a well, including NMR, lithogeochemical, and image logs. To ensure a more reliable analysis of the image logs, specific quality control procedures were applied to both the images and the orientation data. The main steps applied were: (i) Verification, correction, and calibration of the well navigation logs (magnetometers and accelerometers); (ii) Depth and tool velocity correction; (iii) Normalization for the creation of final images (static and dynamic).

Results

During the interpretation of the image logs, the orientations and dip angles of the fractures and breakouts were determined using acoustic images at a scale of 1:20. Three types of fractures were classified (Figure 1): Closed fracture; open fracture; and mixed fracture.

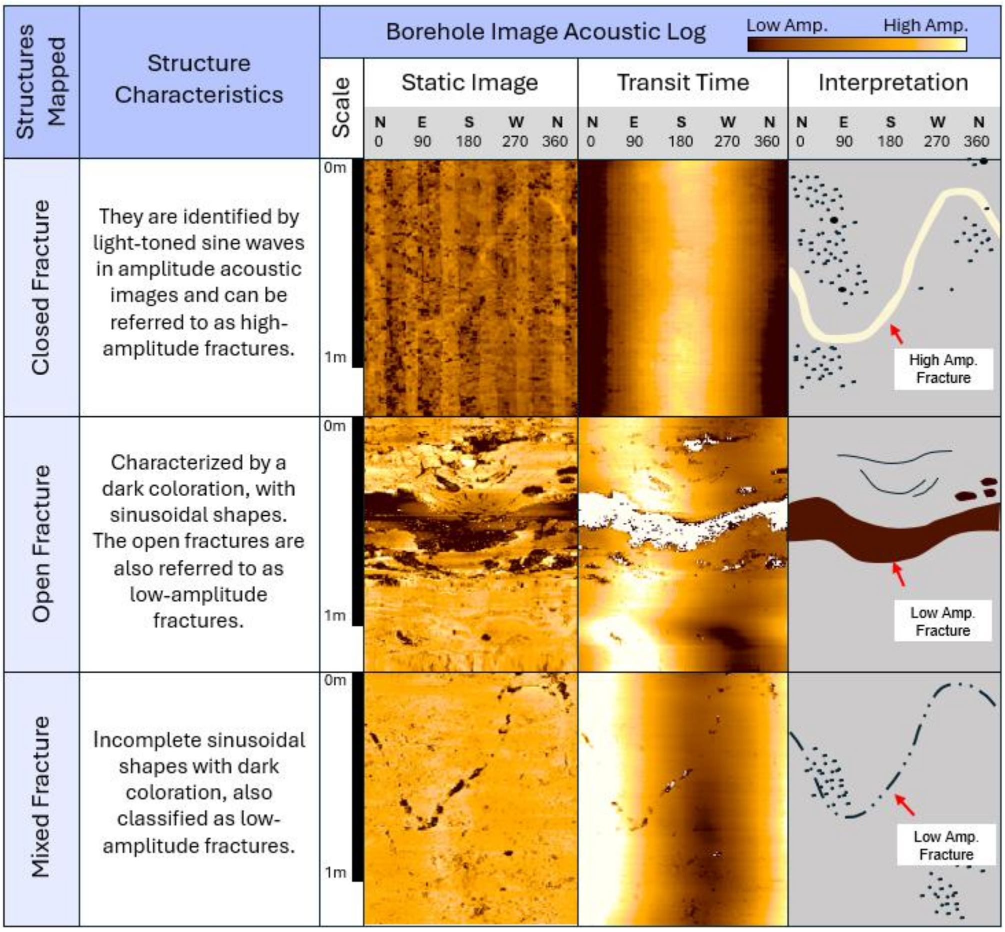

Figure 1: Fracture classification according to acoustic image log and transit time.

The rose diagrams in Figure 2, the strikes of the fractures are plotted according to their distribution and frequency for each formation.

Breakouts are fractures and elongations with a preferential orientation that occur on the wellbore wall. Their direction can be used to determine the stress field acting during drilling, as it is perpendicular to the maximum horizontal stress (Zoback *et al*., 1985). The breakouts were identified through acoustic images and transit time measurements. The results indicate that the direction of maximum horizontal stress is NW-SE for the Barra Velha Formation and W-E for the Itapema Formation. Furthermore, it was observed that the Barra Velha Formation exhibits larger intervals of breakouts.

The structural analysis revealed different types of fractures with distinct orientations at the Barra Velha and Itapema formations, as well as variations in the predominance of these types. For the Barra Velha Formation, a higher occurrence of mixed fractures was observed, which exhibit two preferred directional trends, N-S and NE-SW, indicating bimodal structural behavior. In contrast, at Itapema Formation, the mixed fractures show a dominant orientation in the northeast-southeast (NE-SW) direction, suggesting a more defined tectonic control in this location.

In terms of open fractures, there is a clear difference between the two successions. In the Barra Velha Formation, these fractures predominantly exhibit a west-east (W-E) orientation, which may indicate a distinct tectonic phase or the influence of regional structures. In contrast, in Itapema Formation, the open fractures follow a north-northeast-south (NNE-SSW) direction, suggesting a different tectonic regime compared to Barra Velha Formation.

The closed fractures also exhibit distinct patterns between the two formations. In Itapema Formation, these fractures are more frequent, especially in the lower zones, and display a northwest-southeast (NNW-SSE) orientation. This pattern may be associated with local compressive tectonic stresses. In Barra Velha Formation, closed fractures occur less frequently and follow a northeast-southwest (NNE-SSW) direction, indicating a contrast in both frequency and orientation compared to Itapema Formation.

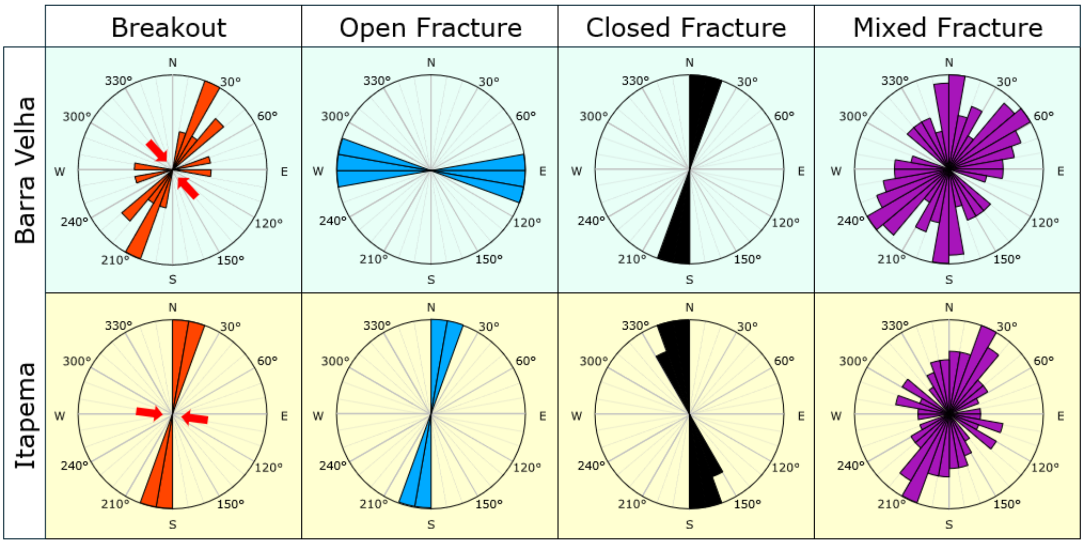

***Figure 2**:* Rose diagrams illustrating the spatial distribution of fractures in Barra Velha and Itapema formations. The red, blue, black, and purple roses represent breakouts, open fractures, closed fractures, and mixed fractures, respectively. The red arrows indicate the direction of maximum horizontal stress.

Discussion and Conclusion

The fracture orientations and types found in the Barra Velha and Itapema formations reflect the Búzios Field's structural complexity and indicate the influence of distinct tectonic regimes or deformational episodes. The observed characteristics of closed and semi-open fractures in the Barra Velha and Itapema formations may reflect different stages of fracturing, where the older fractures correspond to the closed ones, while the open and semi-open types represent the more recent fractures (eg. Lupinacci et al, 2022).

One hypothesis for the abundance of closed fractures in the Itapema Formation is the advanced stage of diagenesis, which results in the infill of preexisting fractures within these carbonates.

Most of the fractures identified in the image logs of the Itapema and Barra Velha formations are in zones with higher silica concentrations (Figure 3). This pattern may be attributed to the mechanical properties of silica-rich intervals, which tend to exhibit greater brittleness and more ruptile behavior compared to rocks with lower silica content. Additionally, the presence of silica may be associated with diagenetic processes, suggesting the action of silica-enriched fluids channeled through fault and fracture systems during late-stage diagenesis (La Bruna *et al.*, 2021; Lima & De Ros, 2019).

Silicification tends to reduce the original porosity of the rock due to the infilling of pore spaces by silica. However, the data obtained from the nuclear magnetic resonance (NMR) log did not indicate a decrease in porosity, which may be explained by the generation of secondary porosity associated with dissolution and fracturing, which creates preferential pathways for fluid circulation.

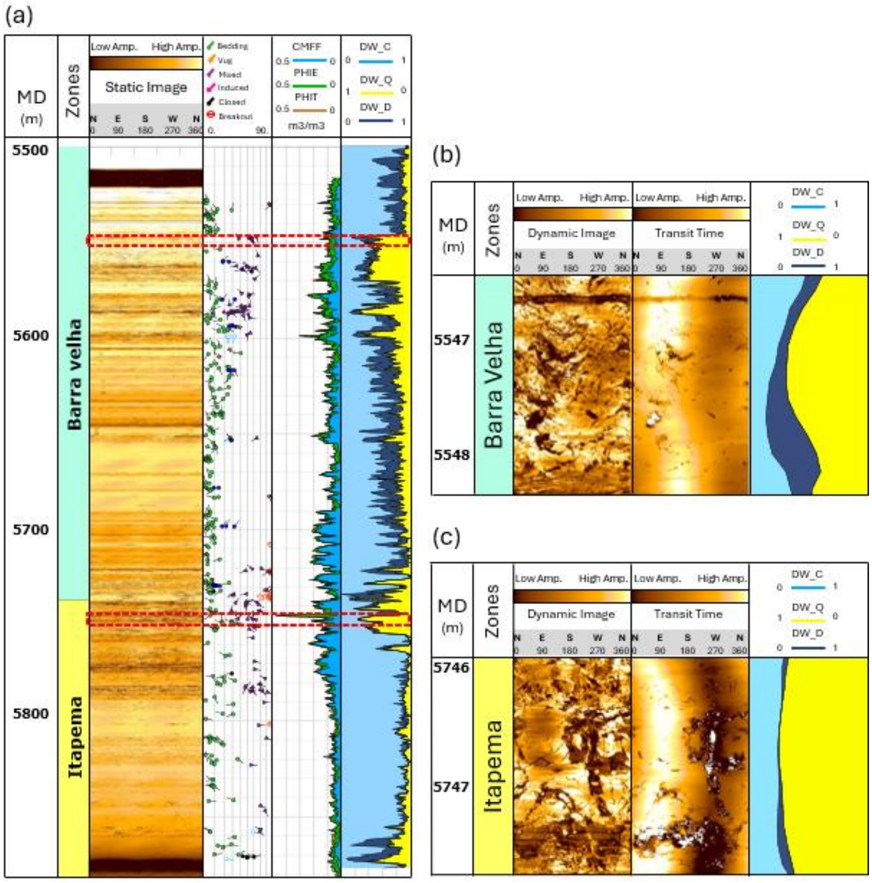

Figure 3: (a) Well 3-BRSA-1195-RJS plot divided into the Barra Velha and Itapema Formations. From left to right: depth track; zones; static image; dip classification; nuclear magnetic resonance (NMR) with total porosity (PHIT), effective porosity (PHIE), and free fluid (CMFF); elemental capture spectroscopy with dry weight calcite content (DW_C), dry weight silica content (DW_Q), and dry weight dolomite content (DW_D). (b) Dynamic image log response in each formation.

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