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Acoustic Image Logging as a Tool for Lithofacies and Silicification Analysis in the Pre-Salt Barra Velha Carbonates, Búzios Field

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Abstract

This study integrates acoustic image and geophysical well logs, and core descriptions from Well 9-BUZ-4-RJS in the Búzios Field, specifically for the Barra Velha Formation. We identified five acoustic facies and seven stratigraphic zones. The proposed facies show strong correlations with observed diagenetic alterations and the primary lithologies. Results indicate that vertical silica distribution in the well region is linked to late-stage fluid percolation, which is controlled by stratigraphic barriers and fault zones. This work advances understanding of silica-influenced carbonate reservoirs and provides a framework to identify these processes in wells with limited core data.

Introduction

Despite nearly two decades since its discovery, the characterization of Pre-Salt carbonate reservoirs continues to present challenges. While detailed core analysis could provide critical insights, its high operational cost often limits acquisition. In this context, borehole image logs (BHI) have emerged as an essential tool for reservoir evaluation and are now routinely acquired. Consequently, recent studies integrating BHI facies analysis with petrophysical and lithological data have advanced, aiming to establish correlations that reflect both the depositional fabric of carbonates and their overprinted diagenetic signatures (e.g., Muniz & Bosence, 2015; Lai et al., 2018; Basso et al., 2022). This study proposes a classification of five acoustic facies in the Barra Velha Formation, based on acoustic image logs, petrophysical data, and core samples from Well 9-BUZ-4-RJS. Located in the Búzios Field's Central High, the well was subdivided into seven stratigraphic zones, each distinctly affected by silicification with direct impacts on reservoir quality. This study hopes to assist in the application of image logs for Pre-Salt reservoir evaluation, especially where core data is limited.

Data and Methods

We classified acoustic image log facies in the well 9-BUZ-4-RJS based on textural aspects, static image amplitude, sedimentary structures, bedding patterns, and petrophysical properties. The study focuses on the Barra Velha Formation. Interpretation of acoustic facies involved the integration of core descriptions, conventional logs, Nuclear Magnetic Resonance (NMR), and Elemental Capture Spectroscopy (ECS). Macroscopic description was performed on approximately 175 m of core samples, equivalent to 95% of the studied section. When available, thin section analyses were used to complement these descriptions, with emphasis on rock texture and depositional fabric. The entire vertical extent of the Barra Velha Formation was logged by the image tool. This allowed depth calibration of the cores with reference to the acoustic image log. In general, we observed a good correlation between structures identified in the cores and those interpreted from image log.

Results

The core consists of 72% reworked carbonate facies, which are represented by grainstones (60%), rudstones (8%), and packstones (4%). The in-situ rocks consist of 12% mudstone lithofacies, while less than 13% of the interval includes shrubstones and spherulstones. The predominance of grainstone lithology over others influenced the dominant lithological

correspondence of facies 1, 2, 3, and 5. The acoustic facies identified, and their key features—including porosity and permeability properties, are presented in **Figure 1**.

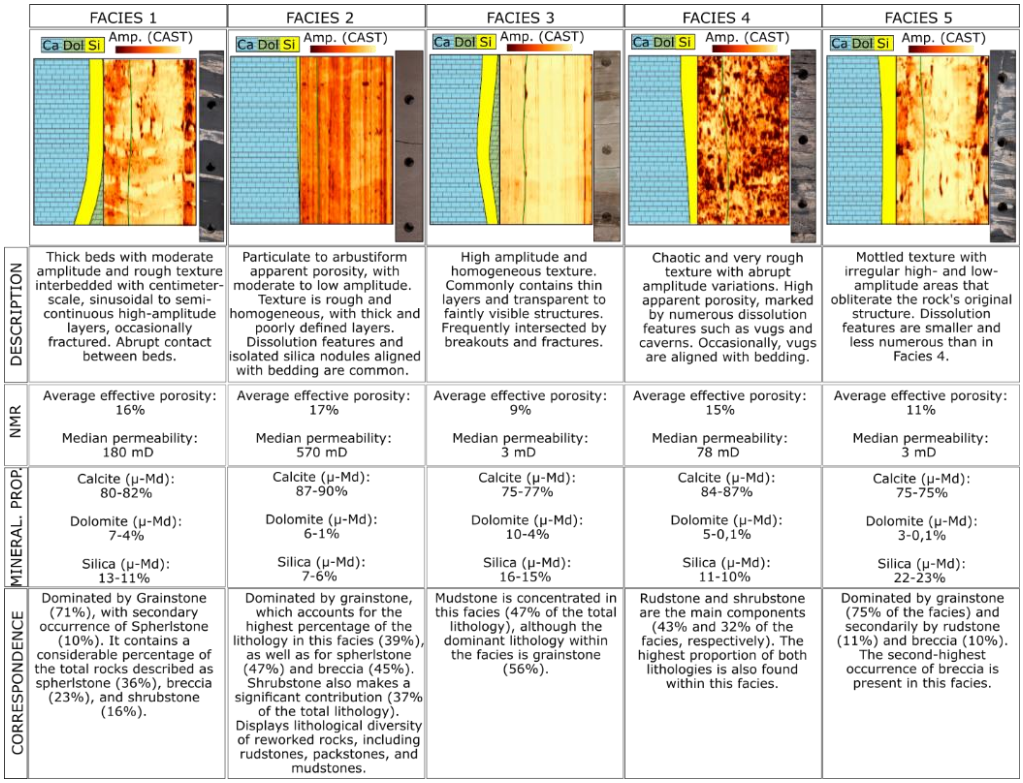

Figure 1: Description of the main characteristics of the identified acoustic facies. The image logs represent 1 m of the borehole wall.

Facies 1 and 5 show spatial relationship and similarities regarding silicified intervals. Facies 1 is characterized by sinuous, fractured, silica-rich layers that in some regions are crosscut by faults, fractures, and more irregular distribution of silicified zones identified as facies 5. This pattern mainly affects initially porous rocks like grainstone and rudstone. In facies 5, pervasive silicification considerably reduced average permeability. Together, facies 1 and 5 represent over 50% of breccia occurrences.

Facies 2 exhibits the highest average calcite values and best permo-porosity characteristics. It is associated with reworked carbonates, a significant presence of shrubstone, and well-preserved original porosity. Silica occurslocally as cement, clasts, or isolated nodules.

Facies 3 is composed of 77% grainstone and rudstone, showing original porosity intensely cemented. This facies contain 47% of mudstone samples, distinguishable mainly by gamma ray peaks. Some thin sections reveal dolomite and microcrystalline silica replacing the former clay matrix. The high silica and dolomite content, associated with low permeability and high acoustic amplitude, reflect intense cementation of lithologies from different depositional environments.

Facies 4 is primarily diagnosed by dissolution features, randomly distributed vugs, giga- to mega-pores, or fenestral porosity aligned with bedding. Poorly sorted rudstones and shrubstone are the main associated lithologies, though it is poorly sampled in thin sections and core. In image logs, abrupt amplitude variations associated with slightly increased dolomite or silica proportions suggest active dissolution and cementation processes.

Seven stratigraphic zones were defined based on bedding direction, acoustic facies, and depositional characteristics (Figure 2).

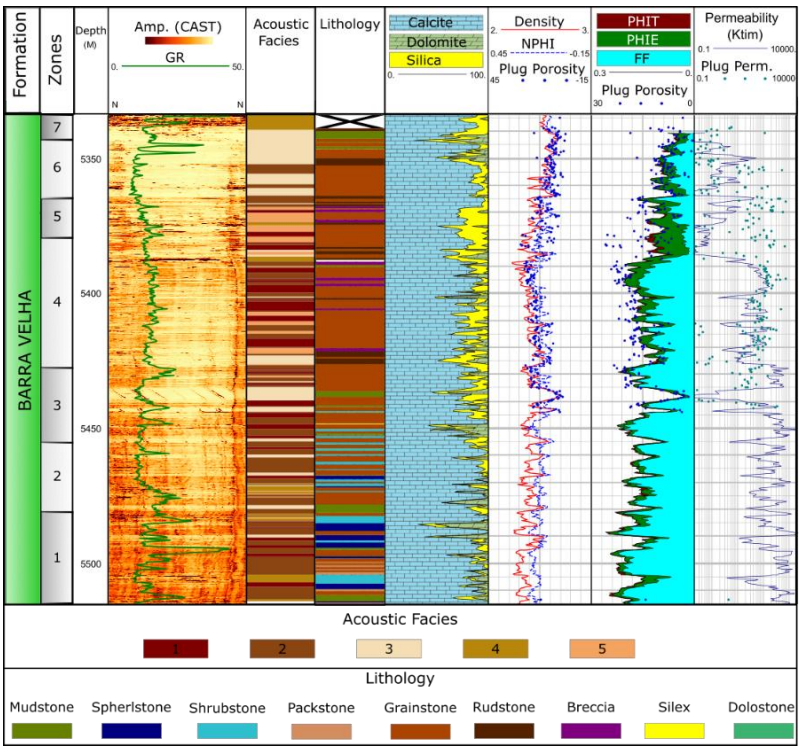

Figure 2: Zonation, facies classification, core description, and interpreted geophysical logs from this study for well 9-BUZ-4-RJS.

Discussions

The interpretation of the acoustic facies revealed a strong correlation between predominant diagenetic alterations and the permo-porosity distribution in the studied intervals. Silica distribution varies along the well and has significant implications for reservoir quality. The lower zones (1 to 3) are the least affected by silicification and correspond to the best reservoir intervals, with high permo-porosity associated with the dominance of acoustic Facies 2.

Silica occurrence is concentrated in Zone 4 and 5, characterized by breccias, fractures, and high silica content intervals linked to Facies 1 and 5. In Zone 4, silica exhibits a stratiform and sinuous pattern (Facies 1), following the bedding of reworked rocks. In Zone 5, pervasive silicification (Facies 5) suggests the action of silica-rich fluids channeled through fault and fracture systems during late diagenetic stages (Lima & De Ros, 2019; La Bruna et al., 2021). These two silica types correspond to type I (stratiform) and type II (pervasive), as described by Fernández-Ibáñez et al. (2022). The spatial relationship between them observed in this study aligns with the conceptual framework proposed by those authors. Two possible events may explain the observed pattern: (i) remobilization of silica I as a potential source for silica II, enhanced by fractures and faults; (ii) external input of silica II by hydrothermal fluids restricted to fault zones.

Although the thick silica layers associated with silica I and facies 1 are interpreted as being of syndepositional/eodiagenetic origin, resulting from changes in lake chemistry (Tosca & Wright, 2018; Fernández-Ibáñez et al., 2022), the nearby occurrence of faults raises the possibility of a hydrothermal origin. Conceptual models of stratigraphy-controlled hydrothermal flow have already been discussed for similar settings (Souza et al., 2021; Basso et al., 2023). Additionally, Zones 3 and 6, which bound the silica-rich zones, exhibit layers with abrupt permeability drops. These units may have acted as stratigraphic barriers, limiting the vertical extent of silicification.

Conclusions

The integrated analysis of acoustic image logs, core descriptions, and geophysical well logs allowed the identification of five acoustic facies and seven stratigraphic zones within the Barra Velha Formation in Well 9-BUZ-4-RJS. Pervasive silicification and hydrothermal fluid circulation were found to have a significant impact on reservoir quality. The vertical distribution of silica indicates hydrothermal fluid channelization through fractures and faults in Zone 5, while suggesting potential stratigraphic control by Zones 3 and 6 over the vertical extent of fluid percolation. These findings suggest a strong structural and stratigraphic control on the distribution of diagenetic alterations. The approach adopted in this study proved effective in capturing the vertical heterogeneity of the reservoir and in identifying key diagenetic processes affecting Pre-Salt carbonates, within the resolution limits of the available data. Furthermore, the proposed textural classification provides a useful framework for future paleoenvironmental and diagenetic interpretations of the Barra Velha Formation.

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