Submission code: BAVDY7XBAR

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Geometry and Distribution of Igneous Intrusive Rocks within the Salt System, Buzios Field, Santos Basin, Brazil.

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Abstract Summary

This study focuses on the Aptian Stage Ariri Formation in the Búzios Field, Santos Basin, and its relationship with igneous intrusions, which can compromise seal integrity, reduce storage capacity, and enhance reservoir porosity in adjacent carbonates through hydrothermal dissolution in the lower layers of the evaporite sequence. Using 3D seismic data (Ocean Bottom Nodes - OBN, 2019) and well data calibration, 65 intra-salt igneous bodies were identified, associated with the Upper Cretaceous (Santonian-Campanian, ~85 Ma) magmatic event. These bodies were classified into seven geometries, positioned in both the upper and lower portions of the evaporitic sequence. The map of intrusive bodies reveals a NW-SE orientation, controlled by pre-existing structures and the complex "multi-Z" salt morphology, which facilitated magma migration. The findings highlight the importance of understanding halokinetic deformation processes associated with volcanic events.

Introdution

During the Upper Cretaceous, the Santos Basin was affected by a major magmatic event, identified in seismic images as extrusive, intrusive, and explosive igneous rocks. In the Buzios Field, igneous bodies were detected within the salt, associated with this magmatic event. However, the presence of igneous intrusions within the evaporites may constrain the sealing capacity of the salt. This study aims to identify Santonian-Campanian igneous sills emplaced within the evaporite column and to classify them based on their geometry. This knowledge provides insights into key aspects of Pre-salt reservoirs, such as variations in CO_2 content in carbonates, fracture network development, and porosity enhancement through dissolution processes, factors that are crucial for understanding reservoir quality and storage potential.

To achieve these objectives, an integration of geophysical and well data was performed, using a 3D seismic volume acquired with Ocean Bottom Nodes (OBN) in 2019, calibrated with data from well BRSA-1195 and wells from the nearby Mero Field. Characterizing these intrusions is fundamental for understanding the structural controls on magma migration and their relationship with the tectono-sedimentary evolution of the basin.

Study Area and Geological Setting

The breakup of the Gondwana supercontinent, which occurred during the Early Cretaceous, led to the formation of the South Atlantic Ocean and the conjugate passive margins of South America and Africa (Meisling et al., 2001; Mohriak, 2003). Within this context, the Santos Basin is located along the Brazilian passive margin, between the Cabo Frio High to the northeast and the Florianopolis High to the southwest.

The Buzios Field is situated in the central-northern portion of the Santos Basin, in the southwestern sector of the Cabo Frio High, over the northeastern extension of the External Santos High. A complex arrangement of faults and structural blocks characterizes the current structural configuration of the Buzios Field. Extensional faults trending NNE-SSW and NNW-SSE, with right-lateral oblique displacements, define large structural compartments.

Ariri Formation and Igneous Rocks

The Ariri Formation was deposited between 113-112 Ma in a restricted salt basin, as a result of increased salinity in this isolated environment (Moreira et al., 2007). It is composed of halite, anhydrite, carnallite, sylvinite, and tachyhydrite, organized in evaporitic sequences whose deposition was mainly controlled by variations in marine water input, possibly associated with fourth- and fifth-order eustatic oscillations. The percolation of saltwater throught seepage processes is thought to have contributed to the formation of thick and complex layers of magnesium- and potassium-rich salts (Jackson et al., 2000).

However, the exact age of deposition of the Ariri Formation remains a subject of debate. Interpretations based on high-resolution carbon isotopes suggest an age between 125 and 130 Ma, while ^{40}Ar-^{39}Ar dating indicates an interval, between 116 and 111 Ma (Tedeschi et al., 2017).

Located west of the Mero Field, the Buzios Field shares the same geochronology as the igneous rocks of the Santos Basin, which were divided into three magmatic cycles by Gordon et al., (2023). The third cycle, from the Late Cretaceous to the Paleogene, is characterized by alkaline intrusions along regional lineaments. The igneous rocks present in the Mero Field and Libra block show compositional and age variations influenced by tectonic compartmentalization (L. C. de Oliveira et al., 2024; Rancan et al., 2018; Zhao et al., 2019).

These rocks are organized into two distinct cycles (Rancan et al., 2018). The first, from the Barremian to the Aptian (~130 Ma) and the second, from the Santonian to the Campanian (~85 Ma), includes hypabyssal alkaline rocks such as diabases, gabbros, and lamprophyres, mainly described in the Barra Velha Formation.

Metodology

The analysis was based on a 3D OBN seismic volume, acquired in 2019, covering an area of over 1,600 km² in the Buzios Field. The interpretation involved mapping the horizons, including the base and top of the salt, as well as intra-salt sills, in both the lower and upper portions of the evaporites.

Igneous bodies were identified based on high-amplitude reflections. A low-frequency spectral decomposition seismic attribute was used to enhance the responses associated with the sills. After detection, the bodies were modeled and integrated with data from well BRSA-1195. To validate the interpretations, igneability (Oliveira F. et al., 2022) was calculated and compared with lithogeochemical profiles.

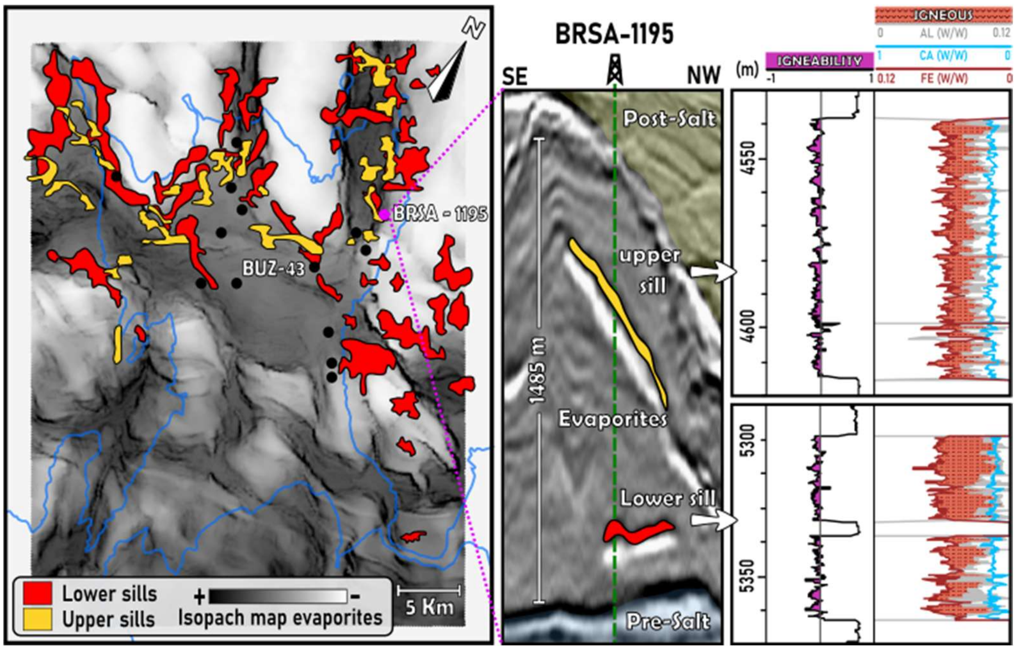

Figure 1: On the left, isopach map of the evaporites from the Ariri Formation showing the location of the sills. On the right, interpretation of the sills in well BRSA-1195 and calculation of ingneability for the identified sills along with their respective lithogeochemical analysis.

Results

The thickness map of the Ariri Formation reveals a predominantly north-to-central salt flow pattern within the field. As shown in Figure 1, the thickest salt areas are concentrated in the northern region, aligned along a NW-SE trend, where the minimum thickness of the evaporitic sequence reaches approximately 20 meters. Although this study does not primarily focus on evaporite depositional cycles, the sedimentation framework proposed by Teixeira et al., (2020) was adopted, which defines four sedimentary cycles (C1, C2, C3, and C4). For each cycle, the main facies - anhydrite, halite, tachyhydrite, and carnallite - were considered, as well as their respective seismic impedance responses: positive amplitude peaks for the halite–anhydrite sequence and negative peaks for halite associated with residual salts such as carnallite and tachyhydrite. Within this framework, the location of the mapped igneous sills, both at the base and top of the evaporitic sequence, corresponds to cycles C1 and C3. In both cases, the sills are emplaced within thick halite layers.

Seismic interpretation enabled the identification of approximately 65 igneous intrusions, with 44 located in the lower part of the evaporitic sequence (C1) and 21 associated with cycle C3. These intra-salt sills are mostly concentrated in the northern portion of the field and exhibit a preferential NW–SE orientation, consistent with pre-existing structures and tectonism associated with the pre-salt system. Conventional and lithogeochemical data from well BRSA-1195 were produced to validate the seismic mapping of the sills. Following the methodology proposed by Oliveira F. et al., (2022), three igneous sills were identified: two in the lower portion of the evaporitic sequence (C1), each with an approximate thickness of 25 meters, and one in the upper portion (C3), with a thickness of approximately 75 meters. At the seismic resolution scale, the two basal igneous sills located between depths of 5300 and 5360 meters present strong positive amplitudes, in agreement with expected impedance contrasts.

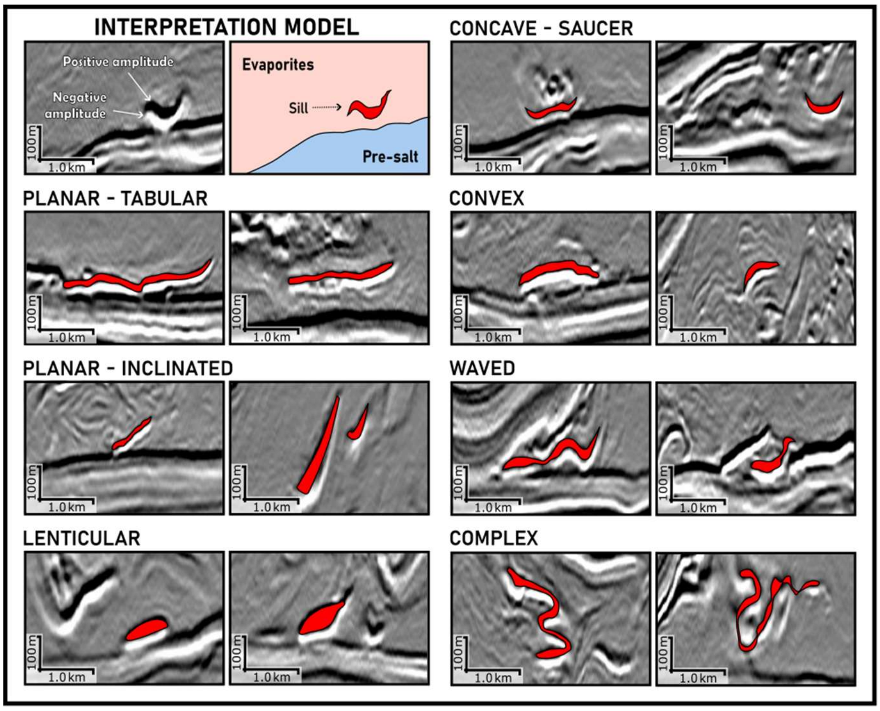

Figure 2: Interpretation model and classification of the seven sill geometries identified within the intra-salt interval.

Based on their seismic amplitude responses and morphologies, the sills were classified into seven geometric categories (Figure 2): planar-tabular (concordant segments parallel to the base of the salt), planar-inclined (concordant but inclined segments within the halite), lenticular (alternating concave and convex curvatures), concave or saucer-shaped (concordant segments with upward-pointing tips), convex (downward-pointing tips), waved (tips alternating up and down, forming an S-like shape), and complex (combinations of multiple segments with varied angular and morphological characteristics). Figure 2 shows an interpretative example of an intrusive sill within the evaporitic sequence, in which the entry of the intrusive rock into the halite is marked by a positive amplitude peak followed by a negative peak.

$^{40}Ar/^{39}Ar$ dating from Well BRSA-1322 in the Mero Field, which shares the same structural trend as the northern Buzios Field indicates that the alkaline igneous sills were emplaced during the Santonian–Campanian, with an estimated age of ~85 Ma. Furthermore, it was observed that these igneous intrusions explored the “multi-Z” geometry of the salt as preferential migration pathways, indicating that the complex morphology of the evaporitic layer acted as a primary control on magma emplacement.

Conclusion

The integrated analysis of geophysical and lithogeochemical data from the Ariri Formation allowed the identification and classification of 65 intra-salt igneous sills into seven distinct geometries: planar-tabular, planar-inclined, lenticular, concave (saucer-shaped), convex, wavy, and complex. These intrusions are mainly concentrated in cycles C1 and C3, emplaced within thick halite layers, preferentially oriented in a NW–SE and N-S directions, controlled by pre-existing structures and the “multi-Z” salt morphology, which acted as a primary guide for magma migration and emplacement. Related to the igneous magmatic event, Santonian–Campanian (~85 Ma), these intrusions disrupted salt layers, creating convolute salt morphologies inside the evaporite sequence. Igneous bodies, in some cases, apparently had their distribution influenced by halokinetic deformations, highlighting the role of different salt composition as an important guide driven intrusive lavas through the stratigraphic evaporitic sequence in the Santos Basin. Two main assemblages of intrusive bodies were mapped within the evaporite sequence, one at the base and another at the top of the sequence. The basal sill system spread from the northern area to the central portion of the oil field structure, whereas the upper sill system is restricted to the northern part of the Buzios field.

References

Gordon, A. C., Mohriak, W. U., Stanton, N., & Santos, A. C. (2023). Magmatic cycles in Santos Basin (S.E. Brazil): Tectonic control in the temporal-spatial distribution and geophysical signature. Journal of South American Earth Sciences, 121, 104111.

Jackson, M. P. A., Cramez, C., & Fonck, J. M. (2000). Role of subaerial volcanic rocks and mantle plumes in creation of South Atlantic margins: implications for salt tectonics and source rocks. Marine and Petroleum Geology, 17(4), 477–498.

Meisling, K. E., Cobbold, P. R., & Mount, V. S. (2001). Segmentation of an Obliquely Rifted Margin, Campos and Santos Basins, Southeastern Brazil. AAPG Bulletin, 85(11), 1903–1924.

Mohriak, W. (2003). Bacias Sedimentares da Margem Continental Brasileira. 87–165.

Moreira, J. L. P., Madeira, C. V., Gil, J. A., & Machado, M. A. P. (2007). Santos basin; [Bacia de Santos]. Boletim de Geociencias Da Petrobras, 15(2), 531 – 549.

Oliveira, L. C., Penna, R. M., Rancan, C. C., de Oliveira Carmo, I., & Marins, G. M. (2024). Seismic interpretation of the Mero Field igneous rocks and its implications for pre- and post-salt CO2 generation – Santos Basin, offshore Brazil. Marine and Petroleum Geology, 163, 106775.

Oliveira, F., Gomes, R., Calonio, L., Silva, K., Carmo, I., Bittencourt, B., Imbuzeiro, B., Silveira, C., Silva, C., & Freire, A. F. M. (2022). Igneability feature: an effective, easy and low-cost way to identify basic igneous rocks using wireline well logs in open hole wells. Brazilian Journal of Geophysics, 40.

Rancan, C., Oliveira, L. C. de, Carmo, I., Marins, G., Pessoa, V., Andrade, H., Penatti, A., Borges, T., Silva, R., Carlotto, M., Basetto, M., & Zanatta, A. S. (2018, November). Rochas ígneas do Bloco de Libra, Bacia de Santos. 49 Congresso Brasileiro de Geologia.

Rodriguez, C. R., Jackson, C. A. L., Rotevatn, A., Bell, R. E., & Francis, M. (2018). Dual tectonic-climatic controls on salt giant deposition in the Santos Basin, Brazil. Geosphere, 14(1), 215–242.

Tedeschi, L. R., Jenkyns, H. C., Robinson, S. A., Sanjinés, A. E. S., Viviers, M. C., Quintaes, C. M. S. P., & Vazquez, J. C. (2017). New age constraints on Aptian evaporites and carbonates from the South Atlantic: Implications for Oceanic Anoxic Event 1a. Geology, 45(6), 543–546.

Teixeira, L., Lupinacci, W. M., & Maul, A. (2020). Quantitative seismic-stratigraphic interpretation of the evaporite sequence in the Santos Basin. Marine and Petroleum Geology, 122, 104690.

Zhao, J., Oliveira, M. J., Zhao, J., Kangxu, R., De Oliveira, L. C., Carmo, I., Rancan, C., & Deng, Q. (2019). Fault Activity and its Influences on Distribution of Igneous Rocks in Libra Block, Santos Basin: Semi-Quantitative to Quantitative Assessment of Fault Activity Based on High-Resolution 3D Seismic Data. 1–8.