Presalt carbonate features interpretation using seismic attributes in a distal portion of the Campos Basin

Paula Carvalho (1,2) *; Lucas Cassino (1); Adriana Silva (1); Polianna Costa (1); Dandara Braga (1); Thales Azevedo (1); Tiago Girardi (1); Vitor Novellino (1); Alexandre Maul (1); Francisco Abrantes Júnior (2,3)

(1) Petrobras; (2) Exploratory Interpretation and Reservoir Characterization Group (GIECAR), Department of Geology and Geophysics, Universidade Federal Fluminense (UFF); (3) National Institute of Science and Technology of Petroleum Geophysics (INCT-GP/CNPQ)

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Abstract

Presalt carbonate reservoirs characterization, in the Brazilian margin, requires an integrated usage of available seismic and well data attached with facies modeling to provide better representativeness and predictability of geological and flow models. Therefore, more reliable volumetric estimates are defined, envisioning better development and production strategies for these accumulations. One of the biggest challenges for activities demanding the use of seismic data is the lack of calibration in areas without drilled wells. It forces interpretations and predictions of reservoir properties to play with uncertainties, especially when combining existing seismic attributes with apart information delivered from already drilled areas, and correlated facies models, as analogs. The objective of this work was the application of 3D seismic attributes in the Campos Basin allowing the construction of more robust and reliable stratigraphic models, through the understanding and detailing of observable geological features from seismic, even with the absence or scarcity of information of drilled wells, in areas where are running the production delimitation and development phases. Therefore, the present study will contribute to the understanding of reducing the main critical uncertainties in reservoir projects´ decision-making processes in any project stage, but especially in the early stage of them, such as sooner, after the discovery of the accumulation.

Introduction

The Campos Basin is located on the southeast coast of Brazilian margin, extending from the north coast of the state of Rio de Janeiro to the south of the state of Espírito Santo. To the north is bounded by the Vitória High (Alto de Vitória-Colatina) and to the south by the Cabo Frio High (Asmus, 1984; Mohriak & Barros, 1990; Mohriak, 2003). It occupies an area of about 100,000 km², from its continental shelf to the bathymetry of 3,000 m (Milani & Araujo, 2003). It is a sedimentary basin in the context of divergent passive margins, formed due to the establishment of an extensive tectonic regime, during the rifting of the Gondwana Continent in the Neocomian, as part of a valley system, preceding the separation of the American and African continents, and the formation of the Atlantic Ocean (Guardado et al., 1988; Guardado et al., 2000).

According to Winter et al. (2007), the Campos Basin can be divided into three supersequences, deposited over basalts of the Camboriú Formation: (i) rift; (ii) post-rift; and (iii) drift. The main producing reservoirs of the presalt section are of Aptian age in the northern, represented by the coquinas of the Coqueiros Formation, and the limestones of the Macabu Formation. These carbonate successions are overlayed by the Retiro Formation, essentially composed of evaporites, which are the main seal of hydrocarbon accumulations (Oliveira et al., 2019).

Wright (2012) studying lacustrine carbonates in rift settings, the same context of the Campos Basin, proposed the division of carbonate facies into four main groups: (i) carbonate build-ups; (ii) shelf, agradational or progradational carbonate sedimentation facies; (iii) extensive carbonate platforms, with plane-parallel architecture; and (iv) muddy lake bottom facies.

The study area of this work is in a distal portion of the Campos Basin. According to Waisman (2008), its main reservoir is intensely silicified presalt carbonate rocks, with vugs, caves, and fractures from Macabu Formation and a reservoir in volcanic rocks, from the Cabiúnas Formation (Luca et al., 2017).

In the study area, information on wells is sparse, as few wells were drilled. Therefore, lateral estimation of properties guided only by them implies large uncertainties (Dubrule, 2003). In this sense, to reduce risks when locating new wells and estimating production curves seismic analysis provides information on the properties of reservoirs in large areas, even playing with huge scenarios of uncertainties (Dillon et al., 2013; Teixeira et al., 2017; Penna et al., 2017; Penna & Lupinacci, 2021). Thus, despite the fact of the wells´ scarcity or the intrinsic bias's information, the use of 3D seismic attributes, by itself or in combination with facies modeling, are tools with huge potential for mapping the internal heterogeneities of the carbonate system, contributing to the understanding of depositional and diagenetic processes, which are rarely seen in outcrops (Henry et al., 2021).

A seismic attribute is understood as any measurement of the seismic data helping to visualize, to improve, or to quantify features of interest during the seismic interpretation process (Brown Jr. & Fischer, 1977). A good seismic attribute is directly sensitive to the desired geological features, or the reservoir´s property of interest, or allows of the definition the tectonic or depositional style/environment and, in this way, gives better chances to infer some features (external and internal) and the related needed information, such as reservoir´ properties (Brown Jr. & Fischer, 1977; Chopra & Marfurt, 2007). According to Barnes (2016), they can be stated also as important "tools" to understand subsurface geology.

The aim of this work is the integration of information from seismic volumes (seismic attributes), with information from wells, looking at the sensitive differences between each observation scale, attached with the known facies models validation, in order to allow better project decision-making during the exploration, delimitation, development, production, and upside development phases.

Methodology

The methodology applied in this work was to generate attributes for a better understanding and identification of the carbonate features present in the Macabu Formation in the study area, in addition to recognizing seismic patterns and integrating with information from wells to deal with the main uncertainties of reservoirs, validating the obtained results with the feasible facies models. Figure 1 summarizes the workflow applied through this methodology.

The seismic volume, as well as the wells, and their curves, were received from the ANP database, as part of the Master Dissertation project, in development at UFF by the first author. A pre-stack 3D seismic volume with Kirchhoff depth migration (KPSDM) was used, with a vertical resolution of approximately 60 meters, according to the chosen resolution criterion (Widess, 1973). After the seismic-well correlation, using three wells with relatively good spatial representation, the stratigraphic interpretation of the seismic horizons, and features observable in the seismic was performed. From then on, seismic attributes were generated and analyzed helping to identify the important carbonate features for the characterization of the presalt reservoir, which we are interested. This helps in the identification process of the main critical uncertainties of the project, according to its stage of them.

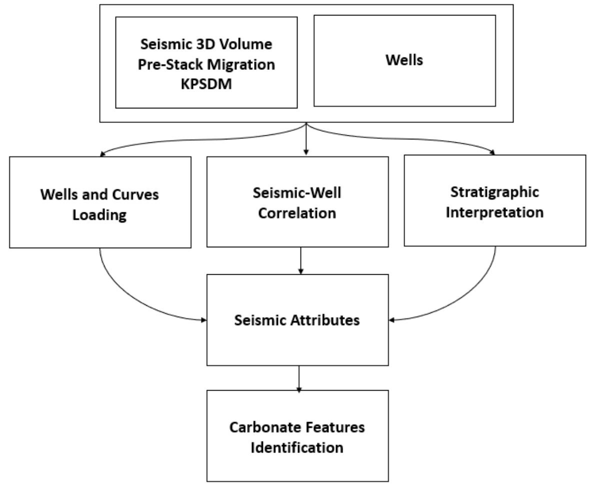

Figure 1: Workflow of the proposed methodology used in this work.

Results and discussions

By analyzing the mapped features in the amplitude seismic volume, reflectors with upward convex geometry and internal bidirectional downlaps were identified, with low to moderate amplitudes representative of the carbonate mounds features. Such interpretation is in according with recent works by Minzoni et al., (2020), Henry et al. (2021), Silva (2021), Macedo (2022), and Paiva (2022). Figure 2 exemplifies a mound´s interpretation using standard seismic amplitude data.

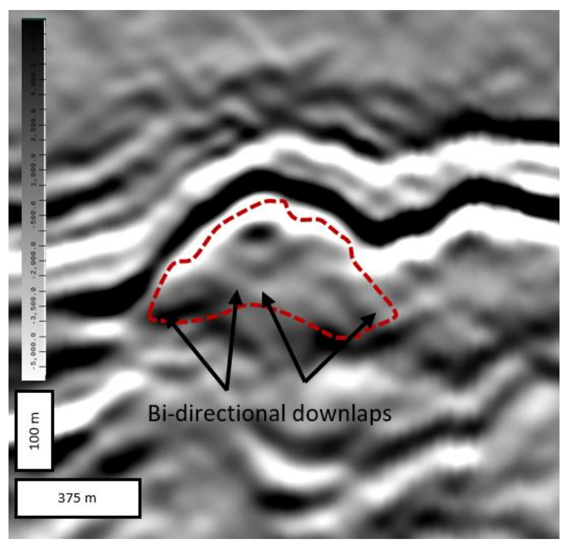

Figure 2: Seismic amplitude section with reflectors presenting convex external geometry and the internally bidirectional downlaps (black arrows). The dotted red curve represents the seismic feature interpreted as a carbonate mound.

After the mounds´ feature identification, the detailing of their internal horizons was carried out, using a seismic inversion volume, superimposed on the TecVA volume (Figure 3). The TecVA attribute was proposed by Bulhões (1999) and published by Bulhões & Amorim (2005). As per the authors, it enables a better understanding of subsurface geology and its depositional processes, since it assumes that every positive or negative seismic reflection has a geological significance and represents interfaces between layers. Dozens of geobodies were automatically mapped (Figures 4 and 5). This attribute was applied to help the description and understanding of recognized seismic patterns.

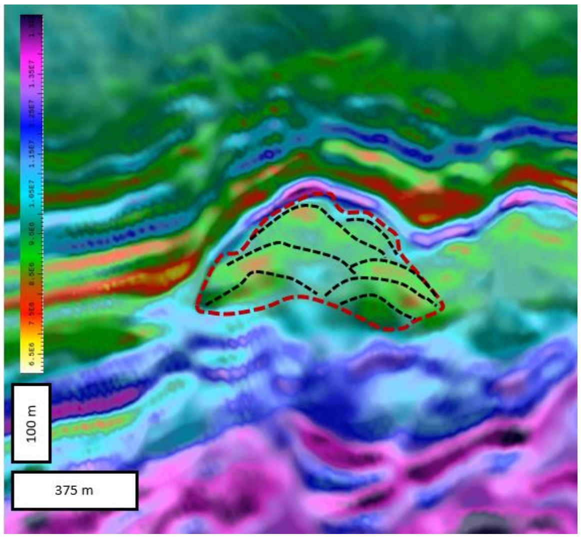

Figure 3: Seismic inversion section, overlaying a TecVA section. It was possible to identify different mound growth patterns within the same feature (dotted red curve), represented by black dashed lines (same detail as shown in Figure 2).

The 3D seismic attributes provid better visualization of the seismic reflection patterns and their terminations, as well as the morphology of the carbonate features. It allows the envelope mapping of the geobodies, and the related internal seismic horizons, in a regional way, covering the entire reservoir accumulation (Figures 4 and 5).

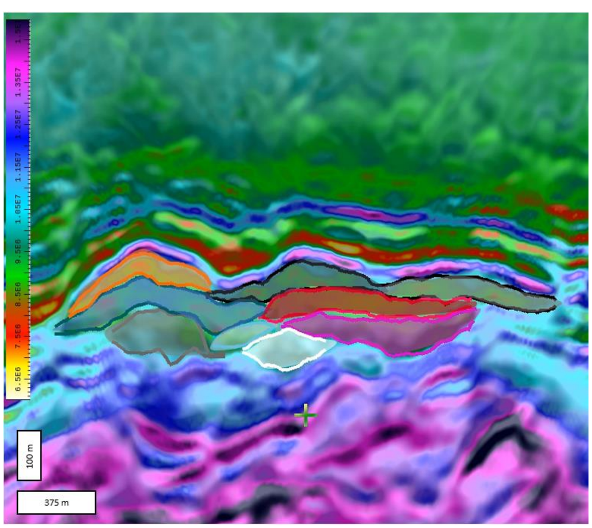

Figure 4: 2D seismic section illustrating the mapping of mounds in the study area. The individual detailing of each geobody was possible by using the combination of seismic inversion and TecVA attributes.

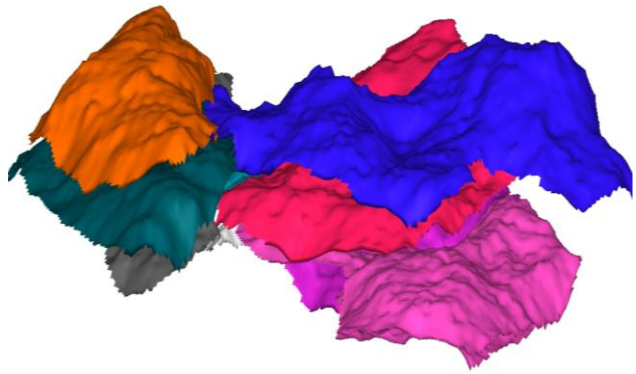

Figure 5: The 3D visualization of the geobodies illustrated in figure 4.

To help the interpretation of the carbonate features and their seismic patterns, following the proposed workflow, the discontinuity attribute was calculated using the methods of Bahorich & Farmer (1995). According to these authors, discontinuities found in the seismic data can be generated due to the presence of faults or stratigraphic characteristics, which modify the seismic traces, reducing the similarity between the neighboring traces. Through the application of this attribute, it was possible to observe a chaotic seismic pattern, with discontinuous to semi-continuous reflectors within the carbonate structures identified as mounds (Figure 6). This chaotic pattern may indicate a bigger internal fracturing of the structure. Comparable results were previously described (Silva, 2021; Macedo, 2022).

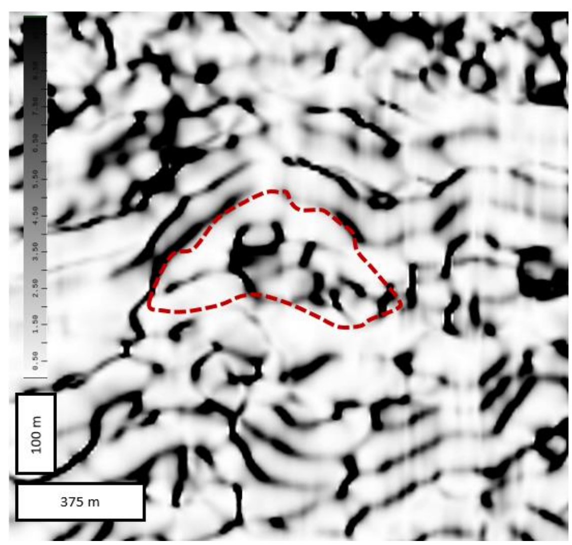

Figure 6: Discontinuity attribute applied to the reference seismic section (same detail shown in figure 2). Observe the chaotic pattern of reflectors internally to the interpreted feature. In dotted red, is represented the seismic feature interpreted of a mound.

Conclusions

Due to the projects having different execution stages, exploration, delimitation, development, production, and upside development, it is important to analyze uncertainties in a robust way, aiming at better decision-making.

The combination of seismic attributes as described in the methodology, specifically seismic inversion + TecVA, enable the identification and detail mound features mapping in the interest area. Furthermore, with the use of the discontinuity attribute, it is possible to help reduce the uncertainties of the geological model, due to a more reliable representation of the internal properties of the reservoir.

Therefore, the greater robustness in the interpretation and spatial characterization of these geological features coming from the combination of all the attributes described in this work is fundamental for better estimations of the volume of hydrocarbon in place of the accumulation, since the largest amounts are in these stratigraphic elements.

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