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A conceptual approach to deal with seismic reservoir uncertainties

Gisele Camargo (Petrobras), Alexandre Maul (Petrobras), Ariely Riguetti (Petrobras), Bruno Lima (Petrobras), Carlos Eduardo Borges de Salles Abreu (Petrobras), Eliane Born (Petrobras), Fagner Almeida (Petrobras),Francisco Dias (Petrobras), Gabriel Cunha (Petrobras), Livia Falcão (Petrobras), Maria Campos (Petrobras), Olivia Ribeiro (Petrobras), Paula Carvalho (Petrobras), Pedro Benac (Petrobras), Thiago Yamamoto (Petrobras), Victor Mund (Petrobras), Vitor Novellino (Petrobras), Thiago Mattos (Petrobras), Yuri Cesar Figueiredo Costa (Petrobras)

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Abstract Summary

Seismic interpretation provides answers to geological questions, based on the analysis of two primary elements: seismic signal and geological pattern geometries. Which. This work greatly affects reservoir volume estimations and, alongside the evaluation of uncertainties associated. It is essential for making assertive and robust decisions in the development and production stages of the studied reservoir fields. However, dealing with seismic uncertainties involves a myriad of approaches. It can be a complex and challenging task since the identification and quantification of each source may influence others. Interpreters leverage their understanding of geological features and their responses in seismic data to navigate the uncertainties encountered in daily operations. This work proposes an organized approach to examine these uncertainties, particularly those related to depth positioning, which significantly affect rock volume assessments and hydrocarbon reserves. In our view, key uncertainties in ultra deepwater fields in the Brazilian Pre-salt, are seismic velocity, seismic resolution and interpretation of reservoir top. The discussion emphasizes the importance of accurately defining seismic events, such as the base of salt in Pre-salt fields, as well as comprehending the implications of resolution and signal interference. We study the interrelations between these aspects by analyzing data from Pre-salt fields in the Santos and Campos basins. This structured approach enhances the reliability of interpretations and provides decision-makers with a more complete understanding of subsurface project risks and opportunities.

Introduction

The seismic interpreter's work must always be driven by geological questions and can generally be subdivided into elements of signal analysis: seismic and geological geometries. Based on the knowledge of geological features, conceptual models and their respective seismic responses, the interpreter selects paths for the interpretation baseline scenario, while also remaining vigilant about the intrinsic uncertainties that are commonly encountered in day-to-day work and routine decisions. This process involves a combination of conceptual knowledge and practical experience. To delve deeper into this issue and broaden the discussion, as well as to demonstrate the impact of some of these interpretation imprecisions, we propose a systematic approach to examine these uncertainties. Firstly, we focus on the realm of seismic data, particularly those related to depth positioning, which can significantly affect rock volume assessments. Secondly, we provide insights into the contributions of geometric interpretations and their potential scenarios in constructing rock properties, with reference to the rock-physics and the conceptual geological model. Uncertainties in positioning related to seismic characteristics from the acquisition and processing stages are identified and compared to well data. It is the interpreter's responsibility to address and quantify the ambiguities associated with each potential area, considering the varying degrees of reliability of the input data. In this context, continuous improvements in seismic imaging have been a primary challenge in both acquisition and processing. Furthermore, interpreters involved in the construction of geological models must appropriately assign levels of confidence uncertainty to their models. One significant uncertainty that greatly affects the models is the volume of rock above the oil-water contact (e.g., Gross Rock Volume, GRV). In this context, the positioning of the reflector at depth becomes a critical variable.

Method

To discuss the aspects of depth positioning, we examine the topic from the perspective of three interrelated variables (Figure 1). While these variables are dependent on each other to some extent, they can be studied separately for a better understanding of each aspect and its contributions to the ranges of uncertainty. Thus, we can identify the three primary sources of uncertainty in positioning: seismic velocity, seismic resolution, and interpretation position.

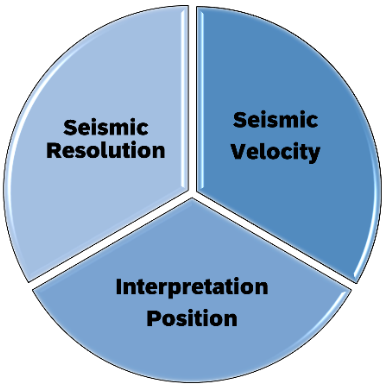

Figure 1: The depth position issue can be observed through three variables: seismic velocity, seismic resolution, and interpretation position.

The first step on depth position issue is address the seismic velocity, thoroughly discussing the positioning of the seismic event to be mapped, such as the base of the salt Santos and Campos basins, ensuring clarity regarding which event is being referred to. Following this, we will address the implications of this event, focusing on resolution and seismic signal interference. Finally, we will explore how to approach it within different interpretation scenarios.

The data from Pre-salt fields in the Santos and Campos basins have been analyzed through this framework. Understanding the intrinsic variables of each of the stages of this triad and their interrelations helps to grasp the magnitude of each of them, and the composition of possible scenarios and end members, with the aim of capturing and quantifying the related uncertainties.

As demonstrated by Camargo *et al.,* 2023 and 2024, differences in model positioning of the top reservoir reflector at varying depths affect both the volume of oil above the fluid contact and the reservoir geometry, which in turn contributes to possible scenarios for the distribution of the reservoir production system.

Seismic velocity is the initial variable to consider. Seismic velocity models have been extensively discussed in the context of seismic processing and well data calibration. Numerous authors have examined their specificities for distinct stratigraphic intervals and the intrinsic correlations between rock physics and geological stratigraphy (Maul *et al.,* 2021; Camargo *et al.,* 2023; Novellino *et al.* 2023; Yamamoto *et al*., 2023).

Advanced tomography studies and various calibration methods can assist in the development of seismic velocity models, providing perspectives on areas with varying levels of confidence. It is also essential to consider the volume of data to be managed and the size of the study areas, noting that the integration of these methodologies leads to more accurate conditions with robust models, allowing vertical positioning variation, and changes in three-dimensional geometry, thereby simulating alternatives for depth seismic images.

For an initial analysis using quality seismic data, an error margin of 3% in average velocity is considered acceptable (Roque *et al*., 2017). From this baseline, we can evaluate the available data, which may lead to either reducing or increasing this uncertainty threshold. The available data can be guided by well profiles or by an understanding of the geological characteristics of the reservoir, and regarding geological structures and composition of the overburden, in particular cases (Camargo, G., 2022 and Novellino *et al.,* 2023)

The second variable is seismic resolution. Seismic resolution as defined for instance by Wides (1973), observes that the interpreted seismic signal is dependent on seismic frequency and, once again, on seismic velocity. The signature of the reflector marking the top of a given reservoir is contingent upon the impedance contrast between the hydrocarbon-bearing reservoir rock and the sealing rock, with the presence of thin layers potentially leading to tunning effects.

In the case of Pre-salt formations, the prominent peak of high positive seismic amplitude that delineates the top of the reservoir is typically attributed to resonance between the signature of the reservoir rock and an underlying thin layer of basal anhydrite (Maul *et al*., 2021). The seismic resolution observed in the most current seismic data shows that the dominant frequencies range from 20 to 30 Hz (Teixeira *et al.,* 2021), which are insufficient to distinguish the signatures of the two interfaces. Variations in the thickness of the basal anhydrite layer throughout the reservoir may significantly impact volumetric calculations.

In regions exhibiting greater volumetric expression, where a thicker basal anhydrite layer is indeed present, the interpreted reservoir top for the reservoir may shift from the high-amplitude black peak, resulting in more substantial volumetric implications. This relationship has been noted, for example, in association with the presence of carbonate mounds where neglecting this observation can lead to misestimation of high-porosity rock volumes, as well as affecting geomechanical rock behavior during drilling operations.

In this context, the selection of mapping criteria in scenarios characterized by changes in the reservoir`s input signature must consider a model of lateral facies variation within this environment. This approach bridges the disciplines of geophysical interpretation and the geological conceptual models that support the reliable understanding of the field, and highlights the connection between seismic resolution and the triad`s subsequent variable: seismic interpretation.

The ultimate variable is seismic interpretation. The selection of the seismic reflector to be interpreted as the top of the reservoir is closely linked to the interpreter's understanding of the possible structures within a given geological environment. This requires careful attention to geometries and body shapes, as well as an understanding of possible seismic signatures in contrast with surrounding rocks. Wells control aids in this comprehension. However, the areal extent and various possibilities are guided by the conceptual models of the field and the rock considered as the reservoir, using seismic data as the observed control.

Areas comprising complex geological structures with multiple physical, chemical and tectonic interfaces (de Oliveira Andrade, P. R. *et al.* 2025), such as the carbonate formations in the Pre-salt of the Saltos Basin, necessitate the consideration of distinct reservoir top models in specific regions of the field. This is particularly pertinent due to the presence of igneous rocks (Oliveira *et al*., 2024) and carbonate mounds (reference).

The same principles apply when selecting the interpretation of the reservoir base and its internal structures. However, understanding the concept from the mapping of the top provides clarity regarding its impacts, and this logic can be extended to other layers and internal structures, such as the “x features discussed by Cruz, N., *et al*., 2023.

Considering the presence of additional structures and development interpretation scenarios may lead to the identification of features that should be incorporated into scenario-building workflows—from geophysical interpretation and geological modeling to the design of different production system concepts.

Conclusions

The seismic interpretation process is intrinsically linked to geological knowledge, focusing on key variables such as seismic velocity, seismic resolution, and seismic interpretation. Itself. Each of these variables plays a critical role in assessing uncertainties related to depth positioning and its impact on reservoir volumetric estimations. The integration of advanced seismic processing techniques and well data calibration enhances the reliability of seismic velocity models, while careful consideration of seismic resolution enables better distinction between reservoir interfaces.

Additionally, the interpreter's ability to recognize complex geological structures and their seismic signatures is essential for accurate mapping and geological modeling.
By adopting a structured approach to analyze and understand these interrelated variables, geophysicists can better quantify uncertainties and develop more robust geological models. This, in turn, facilitates informed decision-making regarding reservoir management and exploitation strategies. Ultimately, a comprehensive understanding of these factors is crucial for optimizing resource extraction and ensuring the sustainability of hydrocarbon production in complex geological settings.

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