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Identification of Geological and Geomechanical Risks: Implications for cost reduction and value maximization in the Pre-Salt Projects of the Mero Field, Santos Basin

Matheus Felipe Stanfoca Casagrande (Petrobras), Alexandre Pinho (PETROBRAS), Paulo Roberto Evelim Borges (Petrobras), Rodrigo Ruan Silveira de Souza (Petrobras), Rodrigo Macedo Penna (Petrobras), Paulo Thomas Koch (Petrobras), Alan De Souza Lameira (Petrobras)

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Abstract Summary

Drilling wells in the Mero field has been challenging due to complex geology and critical geohazards along well trajectories. From 2015 to 2020, about 12 wells were lost, and several others faced delays, resulting in increased costs and postponed development and production projects. Aiming to mitigate these issues, an integrated model that considered key geological and geomechanical characteristics of the post-salt, salt, and pre-salt intervals was considered. A new interpretation of horizons and faults and stratigraphic correlations from well data were made, creating a framework with eight stratigraphic zones in the post-salt, modeled using techniques typically reserved for reservoir modeling. In the salt layers, facies were modeled through seismic inversion, while the pre-salt utilized the current reservoir facies model. The interpreted faults defined regions with critical mechanical properties. By analyzing the models and examining the history of analog wells, geological and geomechanical risks were identified. This approach facilitated the adjustment of well trajectories to optimize operations, leading to faster, cost-effective wells, reducing drilling time by 30% and saving a significant amount of money in rig rentals from 2020 to 2023.

Introduction

As one of the main fields discovered in the Santos Basin, due to its large volume and extensive area, Mero field has gone through an intense campaign of exploratory, development and production well drilling. These wells incur high costs due to their complexity regarding depth, trajectory, and geology. It is a field with ultra-deepwater depths and reservoir targets around 5,500 meters deep, so operational success in well construction significantly impacts the economic outcomes of the projects. As of 2020, 40 wells had been drilled in Mero, of which 12 were lost before reaching the target in the reservoir, and another 17 took considerably longer than expected to be constructed, resulting in losses of millions of dollars.

At that time, efforts were concentrated on identifying the optimal positions to be targeted in the pre-salt reservoir to maximize production and projected recovery factors for the field. However, there was a lack of data regarding the specific characteristics of overburden layers (post-salt and salt intervals) and the information available was not integrated, in a manner that was not being utilized to assess the risks associated with drilling.

Following the operational failures in Mero, there was significant mobilization by Petrobras to understand the causes of the operational issues occurring and to propose solutions that could improve the company's performance in well drilling. One of the initiatives that emerged from this context was the 3D geological and geomechanical characterization and modeling of the overburden, presented in this article, which aimed to enhance the predictability of lithologies, mechanical properties, and stresses along the well path.

Among the most recurrent challenges encountered in the Mero field are bit stalls (a situation in which the drill bit's advancement is interrupted or hindered), drag, and pipe sticking (often associated with borehole wall instability). These instabilities can cause formation collapse and hinder drilling fluid circulation, increasing the risk of operational failures and in the most severe cases, resulting in the collapse of the drilling string.

According to Borges (2024), most of the critical geohazards present in the fields of the pre-salt pole of the Santos Basin are concentrated in the post-salt interval. These include: (i) shallow sandstones with a low degree of burial (< 1,200 m); (ii) cemented and abrasive Cretaceous sandstones; (iii) intercalations of sandstones and shales; (iv) mass transport flows; (v) fault zones; (vi) seabed with high slopes; (vii) pockmarks.

By better predicting and anticipating potential operational risks, it would be possible to optimize trajectories and construction strategies. Thus, this work discusses the methodology used, how these products are utilized, and achieved results.

Study area

Mero field is part of the giant Libra offshore discovery, located in the northeastern portion of the Santos Basin, southeast Brazil. Santos Basin was formed during early Cretaceous Gondwana breakout. The field's main producers comprise bivalve rudstones (coquinas) from the Itapema Formation (Barremian) and shrubs and grainstones from the Barra Velha Formation, although high porosity is also found in others carbonate related facies from Barra Velha Formation (Gomes et al., 2020).

Towards the end of the Aptian, when the evaporitic phase became established, a thick salt sequence from the Ariri Formation was deposited (Pereira and Feijó, 1994). Halite, anhydrite, and a few unusual soluble salts like tachyhydrite, carnallite, and sylvite form the main seal to the hydrocarbons in the Santos Basin (Carlotto et al., 2017). In this paper we will refer to this stratigraphic interval as salt.

After the evaporite sequence deposition, followed the establishment of a marine carbonate platform named Guarujá Formation. After as important transgression, the carbonate platform was covered by shales of Itanhaém and Marambaia Formations and sandstone turbidites os Itajaí-Açu Formation (Moreira et al., 2007). In this paper we will refer to this stratigraphic interval as post-salt.

Method

The employed workflow involved incorporating data from facies logs and stratigraphic markers from wells, interpreted horizons and faults from (Fig. 1) seismic data, and products from seismic inversion to create a 3D geological model of the overburden. This model, along with the geological model of the pre-salt reservoir, previously constructed, served as a control for the subsequent modeling of mechanical properties and in-situ stresses. The outcome of this process was a 3D model that represents the stratigraphic, lithological, mechanical, and stress characteristics in the Mero field region.

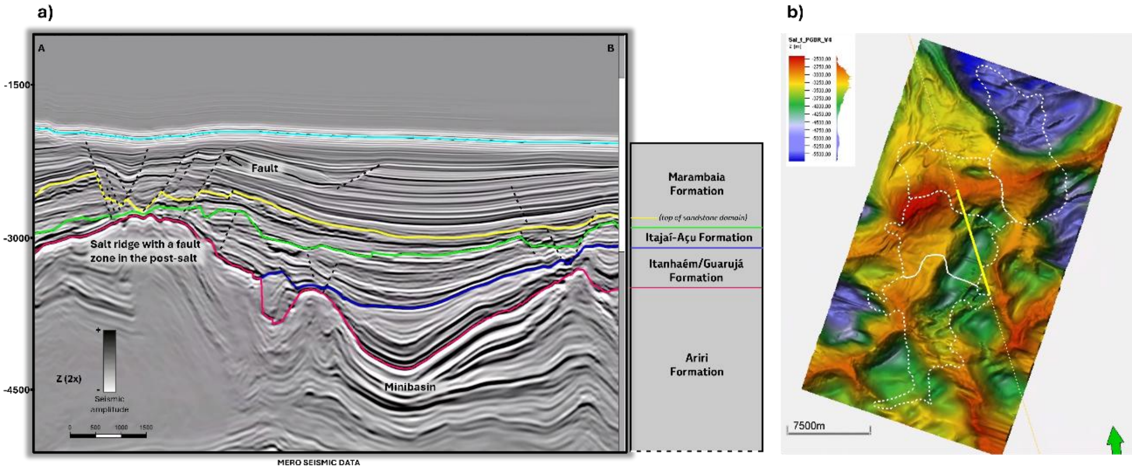

Figure 1: a) Stratigraphic section of the Mero field area, highlighting key formations of the Santos Basin: Ariri, Guarujá, Itanhaém, Itajaí-Açu, and Marambaia, which reflect the region's tectonic and sedimentary evolution, as well as the main horizons used in geological risk analyses. (b) Formation of minibasins in the Santos Basin, created among salt domes and diapirs (warm colors), illustrating the role of salt tectonics in shaping basin structures and sediment accumulation.

The geohazard analysis workflow begins with the examination of the interpreted horizons and faults, which are used to identify and characterize the primary geological structures. This interpretation is then further refined in the vicinity of the well location.

One of the first aspects analyzed is the inclination of the seabed, a crucial factor in ensuring the stability of equipments positioned in this region.
Furthermore, characterizing the lithologies and geological features to be drilled through anticipates operational and geomechanical challenges. The structural setting of the drilling location is also assessed, considering its position relative to minibasins, salt highs, or salt flanks—elements that directly influence drilling strategies.
The number of drilling phases, for instance, is impacted by this structural context. Wells drilled in salt highs, which have a shorter post-salt sequence, generally require fewer phases compared to those located in minibasins or flanks. Correlating with analogous wells previously drilled in the same geological and geomechanical context allows for the identification of recurrent challenges and the prevention of operational problems.
In this manner, the main geological and geomechanical risks are identified and compiled, serving as a foundation for operational planning. These risks are then presented in multidisciplinary meetings, enabling an integrated approach to uncertainty mitigation and more informed decision-making.

Results

The impact of the presented methodology on drilling projects was observed in specific situations, such as in the post-salt section, where, in a mini-basin context, a geohazard related to sandstone water influx was identified, based on similar events recorded in an analogous well. To mitigate this risk, the BOP phase was anticipated, ensuring operational control of the mud weight and preventing the water influx (Fig. 2a).
In the pre-salt section, a geohazard related to a reservoir intensely deformed by faults and fractures, with a high potential of severe mud loss, was mitigated through the design of an inclined well, allowing entry into the target parallel to the main fault. Additional measures, such as strict monitoring of drilling fluid weight and the recommendation to use the MPD (Managed Pressure Drilling), ensured better control over reservoir conditions and enhanced operational safety.
In another case, on the salt flank, a critical risk was identified due to the presence of fault zones and an inclined salt top, which could compromise well stability and drilling trajectory. The adopted solution involved changing the wellhead location and implementing a directional trajectory, diverting it from the most unstable areas and ensuring greater operational safety. Additionally, the change in the wellhead provided a new point with approximately 120 meters less post-salt extension. (Fig. 2b).

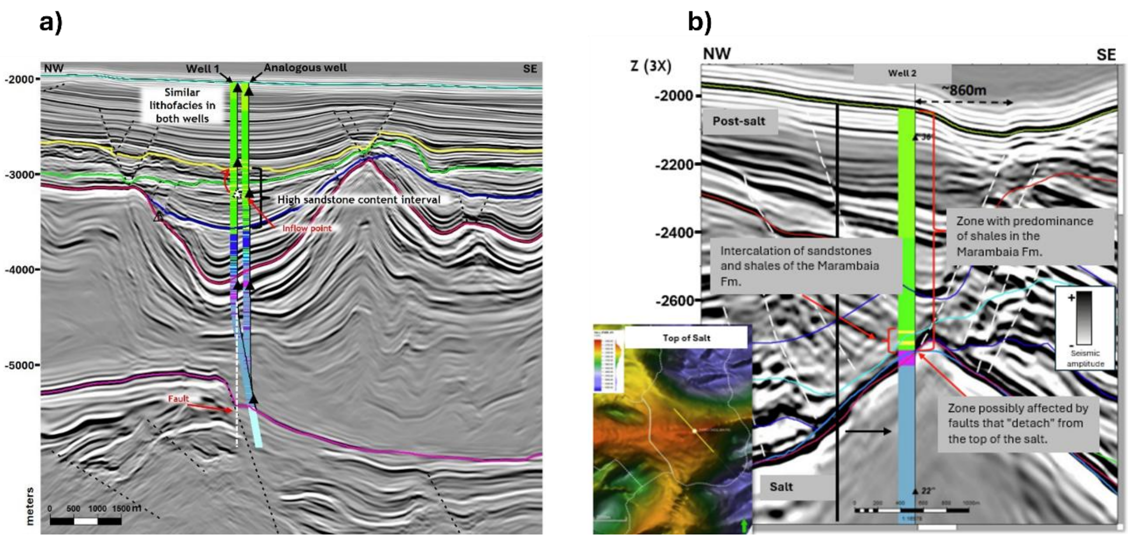

Figure 2: a) Anticipation of the BOP phase in the post-salt section to mitigate the risk of sandstone influx in a mini-basin context, based on previous geohazard events recorded in an analogous well, enhancing operational safety and control during drilling. Deeper, the mitigation of geohazard in the pre-salt section by designing an inclined well, with additional measures like MPD, to ensure

better control and operational safety. Important note: the analogous well is 900 m apart from Well 1 and projected on the seismic section; b) Change in wellhead location and implementation of a directional trajectory to mitigate the risk of well instability caused by fault zones and an inclined salt top on the salt flank.

In the Mero field, case studies have demonstrated that integrating geological, geophysical, and geomechanical analyses was crucial for the efficient planning of operations. By conducting a predictive assessment of the risks associated with the area, it was possible to identify critical zones along the planned trajectories and redesign the well projects, commonly being able to maintain the target position at the top of reservoir. Adjustments to the casing shoe depths, the selection of drill bit types and fluids, and the number of drilling phases were implemented based on multidisciplinary data. These changes not only mitigated geological risks but also optimized operational time and costs, ensuring greater safety and efficiency in the operations.

Conclusions

A geological/geomechanical model that represents characteristics from the seabed to the basement is a valuable tool at various stages of field life. It can be used for forecasting facies, stresses, and faults to be intercepted by well trajectories. Additionally, it facilitates the extraction of mechanical properties and fracture pressure from the reservoir to optimize operations, as well as the definition of limit pressures for injection, fault reactivation, compaction and subsidence analysis due to depletion.

The early prediction of geological and geomechanical risks along the well trajectories, including the multidisciplinary discussions resulting from these studies, enables modifications in well designs, such as head positioning, trajectory, casing depth, and fluid weight, thereby reducing economic losses such as downtime and wells lost before reaching their targets.

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