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Geological Velocity Modeling for Gross Rock Volume Uncertainty Analysis of the Pre-Salt Reservoir in the Marlim Sul Field, Campos Basin, Offshore Brazil

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Abstract Summary

This study investigates velocity modeling challenges with a focus on accurately estimating the depth uncertainty of a top presalt reservoir, which has a thin (~30 m) oil column located beneath complex Albian carbonate rafts and Aptian salt structures. Leveraging reprocessed 2005 streamer seismic data, calibrated well information, and acoustic inversion (Vp), five alternative velocity models were built by selectively incorporating seismic inversion-derived velocities into key geological intervals. A 2023 PSDM-FWI dataset, calibrated to wells, was also used for comparison. The results demonstrate that combining geological insight with inversion-based velocity refinement enhances depth prediction and supports improved development planning. Ongoing node-based seismic acquisition is expected to lower the uncertainties of these findings and inform future drilling strategies.

Introduction

Velocity modeling is crucial for seismic imaging, interpretation, rock property estimation, and depth forecasting, directly impacting hydrocarbon volume estimation (Maul et al., 2021). According to these authors, velocity models are currently built with geological confidence, incorporating heterogeneities, allowing the characterization enhancement of subsurface geology, as seen in the Brazilian Presalt province, comprised by both Santos and Campos basins. In the Campos Basin, Presalt reservoirs that are located beneath complex Albian carbonate rafts and Aptian salt structures, are key hydrocarbon accumulations on Brazil's southeast margin—especially as Postsalt fields production is declining. The heterogeneous geometry of these overburden layers significantly affects velocity modeling, introducing major challenges in accurate hydrocarbon volume estimation (Camargo et al., 2023).

As part of this study, alternative velocity scenarios were created by incorporating geological understanding of the Albian carbonate and Aptian salt layers along with acoustic impedance inversion. The main uncertainty regarding this reservoir is the depth estimation of top. Due to the relatively small oil column average thickness of ~30m, with a maximum thickness of a hundred meters, an uncertainty range of 1% in the velocity modeling might position the top reservoir below the O/W contact leading to the existence or not of a reservoir with hydrocarbon. The velocity model derived from FWI appeared to accurately capture the low-frequency trend. Introducing high-frequency variations into this velocity field affects the depth positioning of the top of reservoir. The results of the alternative velocity models were compared with the previous velocity model, PSDM FWI adjusted to the wells, and with the new FWI processing with well adjustment by tomography.

Seismic Dataset History of the Area of Interest

Two major streamer seismic acquisitions with reservoir characterization objectives were conducted in the Marlim Sul ringfence area, the first in 2005 and the second in 2010. In this study, we focus on the 2005 streamer dataset, which was selected for its superior acquisition parameters coverage. The 2005 dataset, reprocessed in 2020 and later calibrated to well data by the interpreter, served as the main input for the current geological model. The vertical velocity obtained from the 2020 reprocessed data—prior to well calibration—was incorporated into the velocity model presented in this study. In addition, seismic velocity (Vp) was derived from the ratio of acoustic impedance (Zp) to density (ρ), both obtained through elastic seismic inversion. The 2020 velocity model was built by smoothing a legacy model and removing velocity variations from salt and carbonate structures. Delta was estimated from well data, and Epsilon was set as 1.5 times Delta. Multiple tomography iterations were performed in the Postsalt layer, followed by FWI refining the velocity model. Additional tomography iterations improved gather moveouts. Constant velocities of 4480 m/s and 5080 m/s were used for the salt layer and below the basement top, respectively. A new PSDM-FWI processing, completed in 2023, was also employed in this study. The 2023 velocity model was based on a smoothed legacy model, with the removal of velocities associated with salt and carbonate structures. The initial Delta was defined using a gradient between the Seafloor and the Top of the Albian, with a constant value of 0.031 in the Albian layer. Epsilon was set as 1.7 times Delta. The salt and Presalt layers were considered isotropic. FWI was applied to invert the velocity model while keeping the anisotropic parameters fixed. Subsequently, tomography was performed to refine the model, followed by well tie adjustments and recalculation of Delta and Epsilon. Finally, additional tomography iterations were carried out to invert Epsilon and improve moveouts at far offsets. The salt velocity was allowed to vary from 4400 m/s to 4800 m/s.

Both the 2020 and 2023 models are Tilted Transverse Isotropy (TTI) anisotropic velocity models developed through the integration of FWI and advanced tomographic techniques. The main difference lies in the fact that the 2020 model did not include well calibration tomography or inversion of anisotropic parameters. The results from both processing workflows were compared with the methodology presented in this study. All six wells in the study area that penetrated the Presalt reservoir were utilized for this analysis.

Methodology

Considering the Presalt's overburden, in this area of Campos Basin, Albian carbonate and Aptian salt layers are the main geological heterogeneities that will have an impact on the depth positioning of the reservoirs (Novellino et al., 2023). To generate different velocity scenarios, a combination between FWI seismic processing Vp model and acoustic inversion Vp was performed. Table 1 provides a description of the five alternative velocity scenarios generated:

Table 1: Different Vp scenarios.

Scenario	Model description
1	Vp model of seismic processing, calibrated with well velocity from time depth-pairs
2	Vp model of acoustic inversion, calibrated with well velocity from time depth-pairs
3	Vp model of seismic processing with velocity replacement by acoustic inversion velocity in Albian carbonate rafts, calibrated with well velocity from time depth-pair
4	Vp model of seismic processing with velocity replacement by acoustic inversion velocity in both Albian carbonate rafts and Aptian evaporite layer (salt), calibrated with well velocity from time depth-pairs
5	Vp model of seismic processing with velocity replacement by acoustic inversion velocity in the Aptian evaporite layer (salt), calibrated with well velocity from time depth-pairs.

Before modeling, all scenarios required editions of the time-interval velocity by specific regions, determined by surfaces that delimited important velocity domains, to eliminate spurious values in each region. A reliable background range was provided by a statistical analysis of seismic processing interval velocity in these regions. Scenarios 1 and 2 directly used the Vp, respectively, the seismic processing Vp and acoustic inversion Vp. To create scenarios 3, 4 and 5, some combinations of the seismic processing Vp model and the acoustic impedance Vp model were performed. In scenario 3, the Vp model of seismic processing was replaced by Vp model from acoustic inversion velocity only in Albian carbonate layers. In scenario 5, the Vp substitution occurred only in Aptian evaporite layer (salt). And In scenario 4, the Vp substitution occurred in both Albian carbonate and Aptian evaporite layers. The final step of calibration with well velocities, of each scenario, was conducted, by applying the workflow for well-velocity calibration, of the average velocity, in time domain. Kriging with external drift uses the average velocity from wells, as hard data, to calibrate each scenario's average velocity. It is expected that adjusts performed by the kriging process modify each input average velocity field, providing a variability in gross rock volumes (GRV) to be accepted in uncertainty analysis stage.

Results

Among the five scenarios generated using the methodology described above, Scenario 4 was the most representative. It incorporated inversion-derived Vp in the Albian and salt layers, together with the processing velocity in the upper layers, where uncertainty is lower and high-frequency velocity variations are less pronounced. Among the seven scenarios, only few representative ones were selected to be highlighted in the Figure 1: Scenario 1 (the PSDM Vp model with well calibration), Scenario 2 (the Acoustic inversion Vp model with well calibration) and above explained Scenario 4.

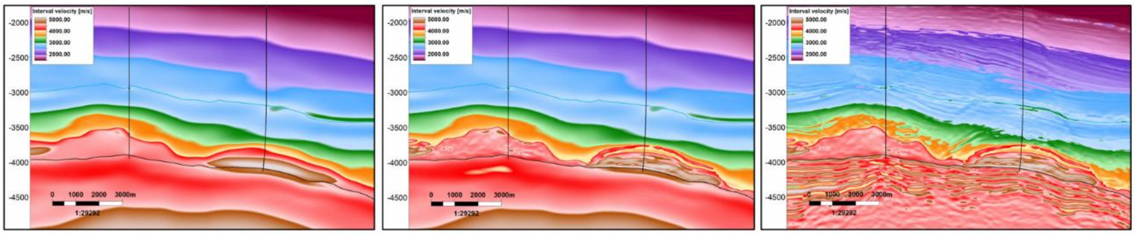

Figure 1: Left – Scenario 1 (Vp model from seismic processing); center – Scenario 4 (Vp model from seismic processing with Vp replacement in carbonate rafts and salt); right – Scenario 2 (Vp model from acoustic inversion). All models calibrated with well velocities from time–depth pairs.

Figure 2 shows a seismic section over two wells, W1 and W2, containing a salt dome and a carbonate raft structure, and emphasizes the variations in the Presalt reservoir top surfaces due to changes in Vp model. The dark green line represents 2020 top reservoir, light green line represents 2023 top reservoir, red lines represent seven modeled Vp scenarios and the blue dotted line represents the oil/water contact.

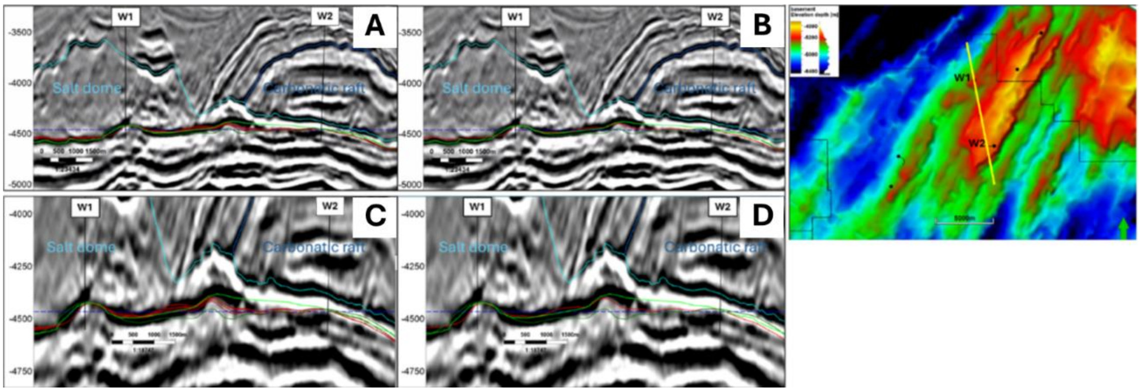

Figure 2: Seismic section through wells W1 and W2 comparing the variations in the Presalt reservoir top surfaces. (A) section with 2020 (dark green), 2023 (light green) and seven scenarios modeled Vp (red); (B) section with 2020 (dark green), 2023 (light green) and elected best scenario modeled Vp (scenario 4) (red); (C) Zoom of (A); (D) Zoom of (B).

The GRV increased 80% from the 2020 PSDM model to the Scenario 4 Model, and 99% to the 2023 PSDM model. The uncertainty at the top of the reservoir varied within a more optimistic range compared to the previous model (Figure 3).

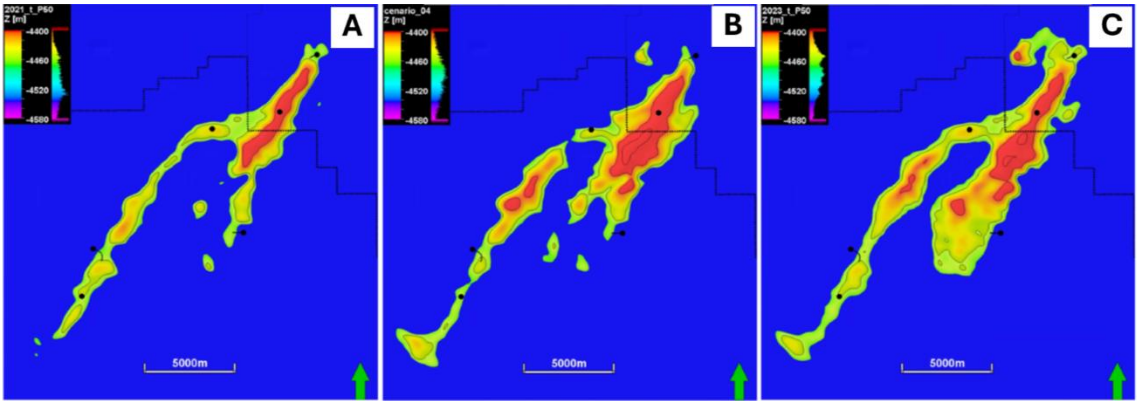

Figure 3: Three versions of the Presalt top reservoir with the O-W surface showing the uncertainties: (A) 2020 model; (B) Scenario 4; and (C) 2023 model.

Conclusions

The velocity modeling results were consistent with the outcome of the new anisotropic 2023 PSDM FWI processing. The five realizations of the velocity model presented above indicate (GRV) with intermediate values between those derived from the seismic data processed in 2020 and the model generated using the reprocessed seismic data from 2023. The results demonstrate a gradual evolution of the GRV, reflecting the progressive incorporation of information from the new seismic processing. Currently, a node based seismic survey is being acquired and it is expected to decrease the uncertainties of these findings and inform future drilling strategies.

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