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Seismic processing strategy for imaging and monitoring of the Búzios field

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Abstract.

The Búzios field, located 180 km off the coast of Rio de Janeiro, remains a pillar of Brazil's oil exploration, with ambitious plans to increase production and reduce greenhouse gas emissions. In addition to the complexities of the carbonate rock matrix, factors such as diagenesis, karst formations and fractures contribute to exploration and production challenges.

Given the geologically highly complex nature of the Búzios field, 4D seismic monitoring is valuable for mapping subtle variations in the reservoir and updating models. Geophysical modeling and results in related areas have estimated weak 4D signals, requiring greater effort in seismic data acquisition and processing.

Advances in computing, as well as FWI research, have enabled velocity inversion at higher frequencies. Migration algorithms such as RTM and Least-Squares RTM have provided good imaging results, but FWI imaging is a result of the derivation of reflectivity from the high-frequency FWI model, providing significant information about the subsurface structure. However, the advantage of FWI imaging goes beyond improving the image. From a 3D perspective, it also helps to better understand the geological context.

To visualize these weak 4D signals, conventional processing with excellence in 4D preprocessing, joint migrations and preconditioning for future inversions is required. In addition to the data processing effort, a joint 4D elastic FWI is planned in parallel, a product that has brought spectacular results for the visualization of 4D anomalies in pre-salt fields.

Introduction

Búzios field is situated 180 kilometers off the Rio de Janeiro coast, beneath a salt layer up to 2,500 meters thick, and is recognized as the largest ultra-deepwater oilfield in terms of oil volume. It features high-quality oil with an API gravity of 26 to 30 degrees and a reservoir thickness of up to 480 meters, covering 852 square kilometers.

The production development plan was approved in 2017, with four production platforms installed by 2019 and a fifth platform beginning operations in 2023, achieving 1 billion barrels produced by March 2024. A sixth platform commenced operations in February 2025, raising production to 800,000 barrels per day.

Buzios presents a series of structural highs and mounds, which are heavily faulted, adding to the complexities of the geological environment. In addition to the complexities of the carbonate rock matrix, there are additional factors such as diagenesis, karst formations and fractures, which contribute to exploitation and production challenges (Brazil et al., 2022).

In such a complex scenario, improving seismic imaging adds value by mapping subtle anomalies in the reservoir. That may be used to optimize the position of new wells, proactively manage Intelligent Completion Valves (ICVs), identify new opportunities for infill wells, update geological and geophysical models, as well as monitor future CCUS operations and geomechanical management to mitigate operational risks.

Regarding seismic reservoir monitoring, geophysical modeling estimated slight (but detectable) 4D signals (Costa et al., 2023), highlighting the importance of using highly repeatable seismic technology such as Ocean Bottom Nodes (OBN). The combined effects of several production effects increase the complexity of interpreting 4D anomalies, making it advisable to put additional effort into the seismic data acquisition and processing, to ensure a signal with a wide frequency spectrum and an enhanced signal-to-noise ratio, resulting in high-quality data that will be effectively used to manage the reservoir.

Advances in high-performance computing and FWI research in recent years have enabled velocity inversion at higher frequencies. Migration algorithms are generally used to produce reflectivity models from the recorded data using the inverted velocity model. Especially in the pre-salt context, RTM and Least-Squares RTM have provided good imaging results. However, these methods rely on the Born approximation, which considers only primary reflections and does not consider nonlinear propagation effects.

Reflectivity is a volumetric distribution of reflection coefficients, defined as the normalized impedance contrast at normal incidence (Zhang et al, 2020), where impedance is the product of density and velocity, involving the dip and azimuth angles of the normal vector to the subsurface reflectors.

Assuming density as a constant, the impedance contrast can therefore be approximated. We arrive at the method called “FWI imaging”, the derivation is performed to obtain that reflectivity from the high-frequency FWI model.

Due to the additional illumination of wave energies other than primary reflections, such as multiples and diving waves, and the least-squares data-fitting process that balances amplitude and attenuates migration noise, FWI image provides significant information about the subsurface structure and a complementary image to conventional migrations in the most challenging areas.

The advantage of FWI imaging goes beyond the improvement in image. The high-frequency velocity model itself can provide relevant information that helps to better understand the geological context.

Processing flow / products

- **3D Processing**

– 12Hz FWI (1st round)

– Anisotropy Update

– 14Hz FWI (2nd round)

– 14Hz FWI (final)

– 30Hz 3D Elastic FWI Imaging

- **4D Processing**

– 4D Pre-Processing

– Joint Least Squares PSDM Kirchhoff

– Joint Least Squares PSDM 45Hz RTM

– 4D Elastic Conventional/Joint FWI Imaging 30Hz

– Pre-conditioning for 4D Seismic Inversion

Why Elastic FWI?

In the presence of large impedance contrasts, such as those related to top of salt and igneous rocks, elastic effects (strain/stress effects, wave mode conversions, phase changes and event polarity flip) are expected. The acoustic FWI approximation loses accuracy in velocity inversion when compensating for phase variations caused by elastic effects on velocity as if they were caused by kinematic errors. In this case, the use of an elastic propagation engine results in a more accurate inversion (Wu et al., 2022).

Using the velocity model after anisotropy re-trending, elastic FWI is performed up to 30Hz. For elastic inversion, only the P-wave velocity is inverted, maintaining a constant Vs/Vp ratio at a value consistent to the overall ratio extracted from the wells. Thus, at each iteration, Vp is updated and Vs is recalculated according to the above ratio.

Why Joint FWI Imaging 4D?

The term joint in "joint FWI Imaging 4D" means that, instead of FWI being applied independently to the Base and Monitor data (conventional methodology), it should be applied jointly to the Base and Monitor data, in order to increase the 4D signal/noise ratio. This will provide more accurate estimation of velocity changes, improved resolution, noise reduction, and improved subsurface illumination. These improvements make Joint FWI Imaging 4D a powerful tool for seismic monitoring and reservoir management.

Intermediate Results

Figure 1 compares velocities and images from Legacy and a preliminary 14Hz elastic FWI results. The Legacy model (Figure 1a) is considerably smooth, with few noticeable contrasts. The 14Hz e-FWI (Figure 1b) added much detail to the model.

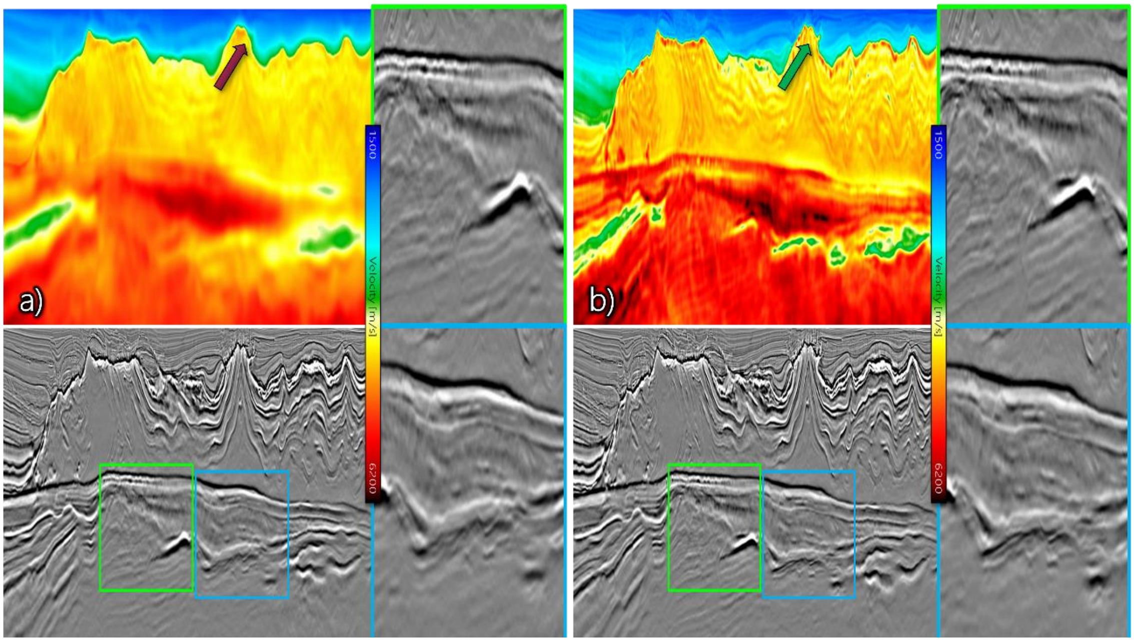

Figure 1: Comparison between the results obtained with the legacy velocity model (a) versus 14Hz elastic FWI (b) for a seismic line. Improvements in geological characterization are also highlighted in the zoomed windows, thanks to the better resolution of the velocity model, including at the top of salt (arrows).

Furthermore, the e-FWI also presents the sediment layers better defined, if compared to the Legacy, and different reflectors are revealed in the pre-salt, providing more continuous pre-salt events and improving resolution.

Conclusions

Elastic FWI resulted in a velocity model with higher resolution than the previous model, allowing for interpretation of detailed geological structures. The velocity model is becoming more realistic, with good overall correlation between the well and the FWI, presenting smaller misties. On average, RTM migration resulted in events with better focus, continuity, and higher resolution.

Provides more Accurate Imaging under highly complex geology as data is elastic. Becomes typically important when impedance contrasts are large (TOS for example)

The joint FWI Imaging 4D approach is expected to enable improved seismic monitoring and reservoir management.

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