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Imaging of challenging hydrocarbon reservoirs in Brazil with multiparameter full waveform inversion

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Summary

The hydrocarbon reservoirs on the Atlantic Margin of Brazil present several key geophysical challenges – in particular in imaging below the complex salt bodies. In this paper we will discuss the application of new imaging techniques on ocean-bottom node (OBN) data from the Santos Basin, offshore Brazil. There are several imaging challenges associated with the large salt structure extending across the study area. Salt complexities create imaging challenges in the pre-salt interval, notably variations in illumination and loss of resolution (blurring).High-end imaging methods such as full waveform inversion (FWI) and least-squares reverse time migration (LS-RTM) are used to solve imaging challenges in such complex geological settings. They aim to provide reliable structural images and stable pre-stack phase and amplitude information for use in quantitative interpretation, reservoir characterization and 4D monitoring studies. Recently, multiparameter workflows have begun to emerge as an alternative solution. These approaches combine FWI and LS-RTM into a single framework where kinematic effects are explained by the background velocity model (FWI) and dynamic effects by reflectivity model (LS-RTM). In this paper, we show results from the application of both acoustic and elastic multiparameter inversion to the OBN dataset described above.

Introduction

The hydrocarbon reservoirs on the Atlantic Margin of Brazil present several key geophysical challenges – in particular in imaging below the complex salt bodies. In this paper we will discuss the application of new imaging techniques on ocean-bottom node (OBN) data from the Santos Basin, offshore Brazil. The OBN dataset used for this study is well known, appearing many times in the literature, located over a producing pre-salt reservoir in the deep water of the Santos basin. The basin is characterized as a typical distension-margin basin. The sedimentary record is divided into three distinct sequences, corresponding to key tectonic phases: rift (Hauterivian to Aptian); post-rift (Aptian); and drift (Albian to present-day). The post-rift phase is marked by carbonate and evaporite rocks, reflecting a tectonic regime with low fault activity and thermal subsidence. The primary reservoirs of the Tupi Field are found in these pre-salt carbonates, known as the Barra Velha Formation. Several wells cover the study area, providing important calibration points for velocity and reflectivity derived from the seismic data. There are several imaging challenges associated with the large salt structure extending across the study area. Salt complexities create imaging challenges in the pre-salt interval, notably variations in illumination and loss of resolution (blurring). Also, strong internal multiples often contaminate the reservoir level, reverberating between the water bottom, salt and intra-salt reflectors.

High-end imaging methods such as full waveform inversion (FWI) and least-squares reverse time migration (LS-RTM) are used to solve imaging challenges in complex geological settings. They aim to provide reliable structural images and stable pre-stack phase and amplitude information for use in quantitative interpretation, reservoir characterization and 4D monitoring studies. Recently, multiparameter workflows have begun to emerge as an alternative solution. These approaches combine FWI and LS-RTM into a single framework where kinematic effects are explained by the background velocity model (FWI) and dynamic effects by reflectivity model (LS-RTM). The concept of seismic scale separation and the multiparameter inversion bring stability and robustness for both properties, minimizing leakage between the two terms. In this paper, we show results from the application of both acoustic and elastic multiparameter inversion (Huang *et al*., 2025) to the OBN dataset described above.

Methodology

In recent years, some notable advancements have been made in the field of seismic imaging concerning the interplay between FWI and RTM. Previously, these two techniques have been used at different stages of the seismic imaging workflow – FWI for velocity model building, and RTM for the imaging stage. However, their formulation is fundamentally linked allowing them to be combined in the same inversion framework, solving for two unknown parameters simultaneously – velocity and reflectivity – as described by the pioneering work of Yang *et al*. (2021). The method comprises two fundamental elements for achieving this: an inverse scattering imaging condition (Whitmore and Crawley, 2012; Ramos-Martinez *et al*., 2016) with a full-wavefield modelling engine based on the two-way wave equation, parameterized in terms of velocity and vector-reflectivity (Whitmore *et al*., 2020). The approach has been extended to the pre-stack domain allowing reflectivity estimates to become angle-dependent (Chemingui *et al*., 2023). This integrated framework not only refines the velocity model but also yields high-fidelity seismic image angle gathers, making it a valuable tool in exploration and reservoir characterization.

Example

A full suite of raw, pre- and post-migrated datasets was available from recent processing that included interbed multiple attenuation and an image-domain, pre-stack LS-RTM. The legacy velocity model was simple but still robust, providing good ties with the well information across the study area. Input to the simultaneous inversion workflow used the legacy velocity model along with raw hydrophone data after corrections for clock drift and water column velocity variations, and simple denoising. The inversion

started with a frequency band from 2 to 5 Hz and progressively broadened the bandwidth as the long wavelength errors were resolved. Results from the simultaneous inversion are shown in Figure 1, compared to conventionally processed results

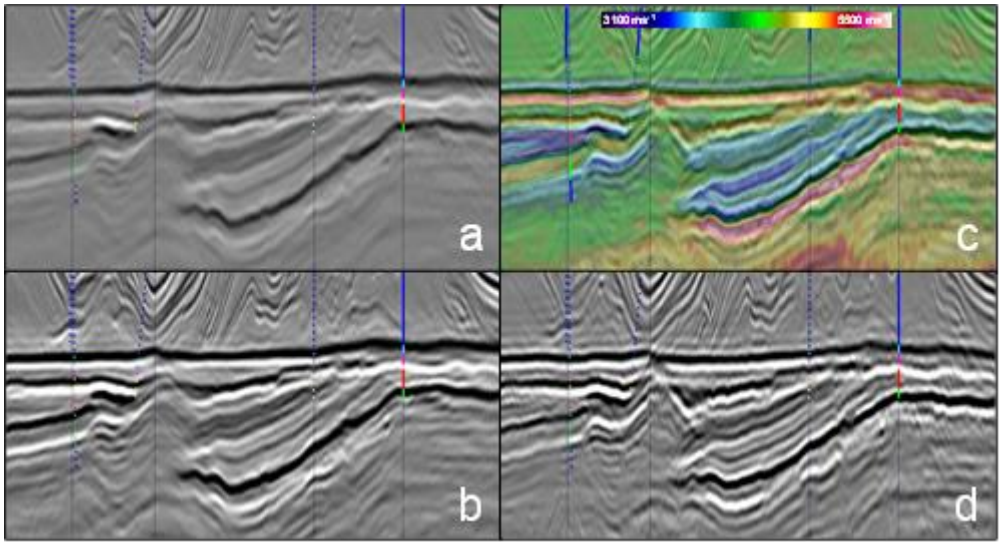

Figure 1 *Comparisons of pre-salt imaging in the dataset between a) RTM, b) image-domain LS-RTM. Panels c) and d) are results from the multiparameter inversion: c) shows the velocity overlaid on reflectivity, while d) shows just the reflectivity.*

Conclusions

An acoustic and elastic multiparameter inversion workflow that simultaneously estimates velocity and reflectivity has successfully applied to an OBN datasets from the Santo basin, offshore Brazil. The results illustrate the potential of this technology to provide accurate imaging and reliable amplitude information in the region. By combining velocity and reflectivity estimation, this workflow can contribute to a deeper understanding of subsurface properties aiding decision-making in exploration and reservoir management.

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