Combination of the Salt Stratifications and the Least-Square Migration to evaluate their Improvements for the Pre-Salt Reservoir Images in the Santos Basin, Brazilian Offshore

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Abstract

This paper presents the benefits of combining geological velocity modelling with Least-Squares Migration (LSM) in the image domain to generate seismic images for the Brazilian Pre-Salt reservoirs. The geological velocity modelling on these areas focuses on the evaporitic section characterization, regarding the incorporation of stratification features presented in this layer into velocity model. We compare the generated results with seismic images created by a velocity model derivative from tomography – which does not have salt stratification representation – and performing a Reverse Time Migration (RTM). In addition, we made a quantitative comparison with a modelled reference horizon to analyze the depth positioning and its amplitude.

Introduction

Over the past few years, tremendous improvements on the quality of seismic images for geologically complex areas have been achieved. One of the main reasons is the effort put on the task of velocity model building (Jones and Davidson, 2014). In Santos Basin Pre-Salt reservoirs, the quality of seismic images increases when accounting for salt stratification into initial velocity models for update processes (Fonseca *et al.*, 2018; Maul *et al.*, 2018a). These models guide the tomographic inversion or FWI to generate more geologically realistic velocity updates prior to the seismic imaging step. Although the quality of the images improves when considering the stratified velocities, poor illumination under the salt bodies still negatively affects the signal response. Recent studies indicate that Least-Squares Migration (LSM) in the image domain represents an advanced tool to boost the signal quality of pre-salt reservoirs (Dias *et al.*, 2018). The LSM attempts to correct distorcions in poorly illuminated areas and improves resolution, both issues related to wave propagation in complex overburden (Nemeth *et al.*, 1999 and Hu *et al.*, 2001).

The velocity model with salt stratification and the LSM algorithm work together looking for to reach the follow achievements: to provide the best image (considering all the relevant geological features) and to ensure the complexity of wave propagation in the inversion process framework. These goals allow a more accurate seismic-driven rock property prediction. Therefore, the combination of both techniques arises as a natural step to be followed in order to achieve reliable subsurface geological information. Here, we present a comparison of two seismic images with different migration velocity models: the first one considers a standard industry approach in building velocity model (i.e. almost constant velocity salt layer updated by tomography), while the second one considers the velocity variation of salt stratification. The first is migrated with Reverse Time Migration (RTM) and the second has the LSM application to enhance signal quality.

Method

Maul *et al.* (2018b) discussed how to incorporate the stratifications inside the salt section using combinations of well logs and seismic attributes as guidance. Figure 1 illustrates the differences from two velocity models: (a) from tomography and (b) incorporating the salt stratigraphy using seismic attributes. For the migration process of legacy data, the combination of rock physics and seismic inversion proved to be valuable for the velocity model building. Figure 2 highlights the results of a Kirchhoff Pre-Stack Depth Migration (KPSDM) section of a Pre-Salt reservoir for cases (a) and (b).

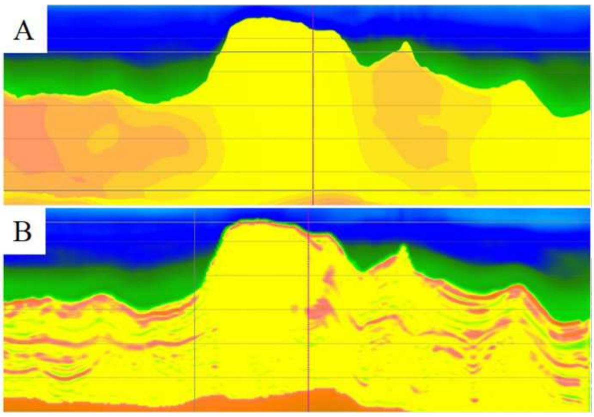

Figure 1: *Type of velocity models used to test the proposed approach:*
A – The tomographic velocity updated model;
B – The velocity model with the stratification insertion.
Adapted from Maul et al. (2018a).

Regarding the seismic image results, even considering legacy data, Fonseca *et al.* (2018) advocated that the combination of rock physics and seismic inversion has strong impact on the velocity model building. Figure 2 highlights the results of a KPSDM section of a Pre-Salt reservoir for cases (a) and (b).

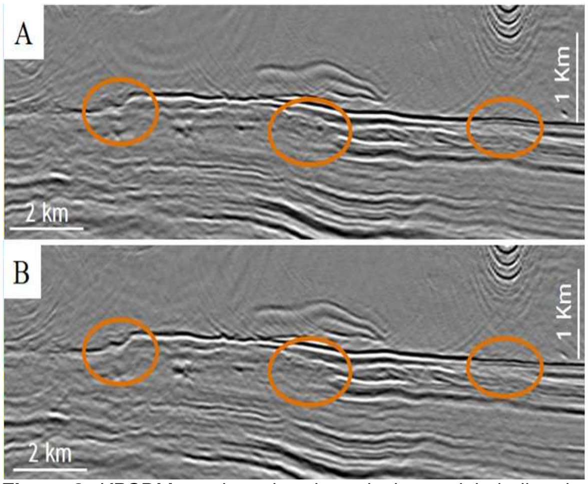

Figure 2: *KPSDM results using the velocity models built using the approaches mentioned in Figure 1:*
A – Using the tomographic velocity model;
B – Using the velocity model considering the stratifications insertion.
Adapted from Fonseca et al. (2018).

Dias *et al.* (2017) emphasized that the use of LSM algorithm could compensate the seismic signal distortions to ensure reliable amplitude responses for seismic images under the salt bodies (Figure 3). Moreover, it enhance the resolution for better definition of thin layers. Here, we propose a step further: to evaluate the benefits of the salt stratification inclusion for the LSM. The adoption of the signal compensation using the stratified model brings significant advantages. Therefore, the models should account this geological feature.

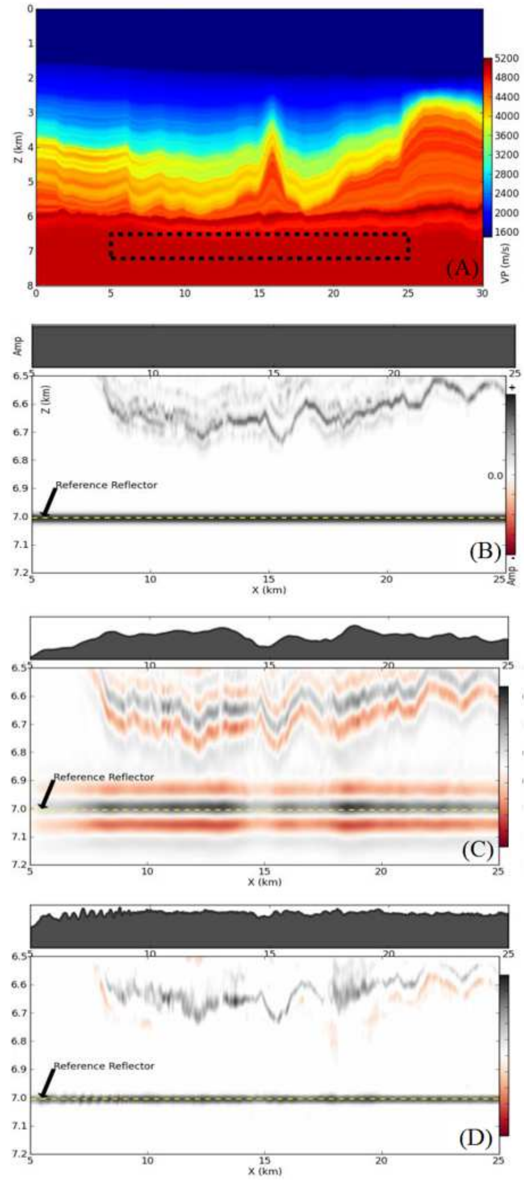

Figure 3: *of Image Domain LSM Application in a synthetic scenario based on Pre-Salt carbonate reservoir in the Santos Basin. (A) Reference model with reservoir inside dashed line; (B) Reference reflectivity for the reservoir; (C) Traditional Reverse Time Migration (RTM) and (D) LSM with sparsity constraint (L1-norm). The top of each figure displays the amplitude extracted on the reference reflector. It is clear the variation of the amplitude observed in the traditional migration (C), which is significantly reduced in the LSM (D). In addition, it is visible the considerable gain in resolution. Adapted from Dias et al. (2017).*

Results and Discussions

Up to now, there are no connections between these two methodological developments. The proposed approach regards the combined use of the stratified salt inclusion in velocity model and the least-squares migration to create enhanced seismic images. With a typical 2D section from a pre-salt play in the Santos Basin, we made an acoustic modelling with two-way wave equation and variable density to generate raw shots from the velocity model. These shots were migrated using RTM and LSM, with two velocity salt models: tomography (without stratification) and stratified velocity inside the salt section. Figure 4 illustrates the velocity model used for the shot generation, the RTM image generated by the salt velocity from tomography, and the LSM generated with the salt stratification inclusion in velocity. In addition, an arrow points a reference horizon as a trough (white) in amplitude.

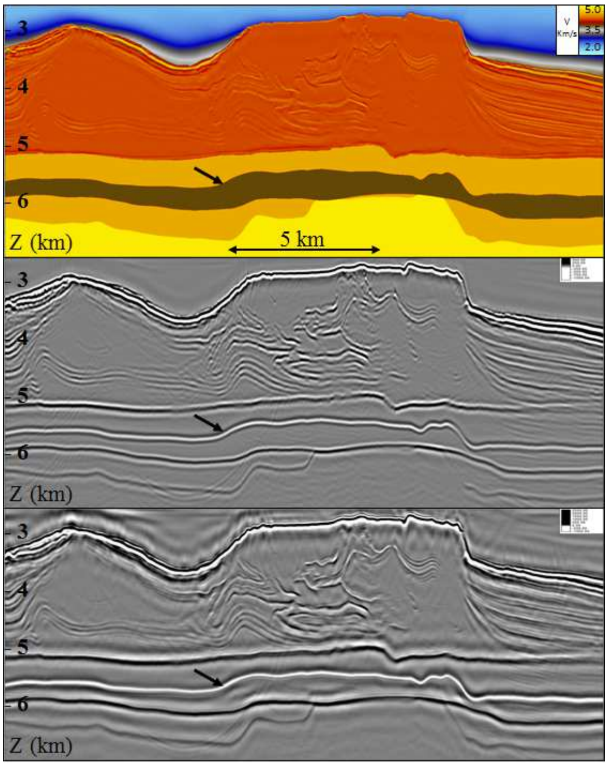

Figure 4: Velocity model with salt stratification (top), RTM image using the original tomographic velocity for migration (middle) without the stratification insertion, and LSM image using velocity model considering the salt stratification insertion for the migration process (bottom). The black arrows represent the reference horizon to be analysed in Figure 5.

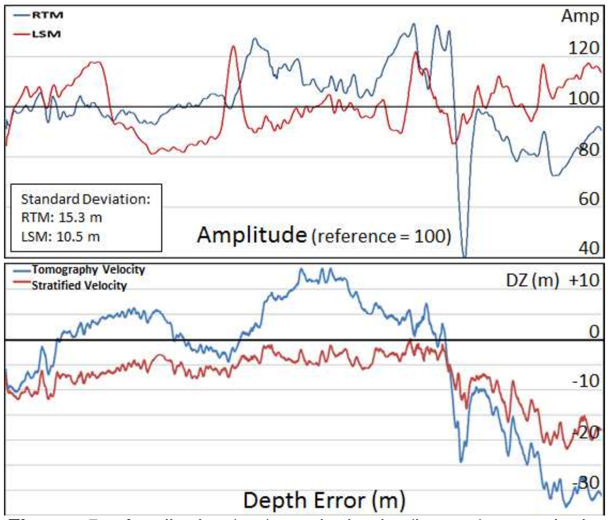

Figure 5: Amplitude (top) and depth (bottom) quantitative analysis of the reference level (horizon) illustrated in Figure 4. The amplitude value for the reference horizon was set as 100. DZ means the depth difference between the modelled level (horizon) and the interpreted one after the migration considering the two velocity scenarios. A positive value means that the interpreted horizon is above the true model horizon.

Figure 5 demonstrates the quantitative analysis on the reference horizon. In the top graph one can notice that we have more reliable amplitude responses, with a reduction on the variance of the true reflectivity values in 53% (standard deviation from the r = 100 reference value from 15.3 without stratification to 10.5 with stratification), when moving from RTM to LSM process. The second one states that the usage of a more variable velocity as in the salt stratification, the reference horizon average depth error presents a reduction of 38% (10.2 m to 6.3 m).

Conclusions

Both velocity modelling with salt stratification and LSM have already demonstrated higher quality results individually. Through the combined application of those approaches, we could observe improvements in the seismic images, with better positioning, focusing, resolution and amplitude balance.

When the final seismic image is more reliable, it brings benefits like structural uncertainty reduction, accurate rock property estimation and identification of more geological features in the reservoirs. This is essential to enhance the reservoir characterization.

Future Works

We should compare the stratified model estimation based on the migrated image output using the tomographic velocity with the true model and the benefits of the LSM image using this estimated velocity field. In addition, we do need to evaluate the Data Domain LSM and the impact of the stratified salt layer.

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