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Tomographic velocity simulation after the seismic migration process: related benefits for dealing with uncertainties of reservoir depth positioning

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Abstract

Reliable velocity models, built under geological criteria, are mandatory for providing accurate seismic images, especially in situations where geological complexity is present. Thick salt layers impose challenges in the seismic imaging beneath rocks, such as those regarding depth-positioning, which have a huge impact on hydrocarbon exploration and production. This is the case for most pre-salt reservoir projects, in which the simple presence of the salt section above the reservoir and the inherent heterogeneities (salt-stratifications) are recorded. In this study, two wells were drilled in the same geological structure, one showing some oil indication and the other with only water indication. it was necessary to find a plausible explanation for this situation. PSDM image provided a pre-salt relatively continuous high, with no indication of spill-point region by the top of reservoir surface, between the different fluids in the wells. The initial idea was to investigate the velocity model from seismic processing, to identify inconsistencies and propose a solution through a more detailed velocity modeling methodology. Our results will show how to deal with this inconsistency (no presence of spill-point) when simulating inverse tomographic inversion for velocity updating.

Introduction

In the Santos Basin, the salt section, deposited in Late Aptian, is called Ariri Formation (Moreira et al., 2007) and it can range from a few meters to about 3 km thick (average of 2,5 km) (Mohriak et al., 2008). The thick salt layer was precipitated under restrictive conditions, in an arid climate, from this hypersaline sea (Karner and Gamboa 2007). Halokinetic forces and extensional process led to formation of complex geological structures, such as diapirs and stratified walls, observable in seismic images and drilled wells (Gamboa et al., 2008). Erroneously, the evaporitic saline section is idealized as a homogeneous section which presents the characteristics of halite mineral (Maul, 2020). As observed in the drilled wells, although halite is the most common facies (80 to 90%), other minerals were identified, such as anhydrite, gypsum, tachyhydrite, sylvite, carnallite, volcanic and calcite (Maul et al., 2018). These authors also organized the salt types into three main groups, regarding the compressional velocity behaviors, having the halite compressional velocity as reference: Low Velocity Salts (LVS), composed by sylvite, carnallite and tachyhydrite minerals (around 5-10%); halite (the reference mineral, with nearly 80%), and High Velocity Salts (HVS), represented basically by anhydrite and few gypsum occurrences (10-20%), according to well's examination.

An understanding and characterization of the geological complexity of the salt layer was mandatory as it has a huge impact on the stratification stage demonstrating what kind of stratification should be inserted and which velocity should be used (Jones and Davison, 2014). In that work, the authors proposed a solution to the main issue, by applying the well-known methodology for salt layer heterogeneities insertion into velocity models through a routine that simulates a tomographic inversion velocity updating. Supported by analysis of well data, the stratification of the homogeneous processing stage velocity model proved to be effective in representing the mineralogic variability present in the saline sequence and consequently, being capable of populating, more precisely, the evaporites' interval velocities. The result "stratified smoothed interval velocity model" has a higher geological behavior and was capable to solve the project's initial issue.

Datasets

The dataset used in this study consisted of 10 wells and a pre-stack depth-migrated (PSDM) 3D seismic data. A commercial seismic processing data which comprised an area of approximately 24,000 km2, was a result of simultaneous seismic processing of three different acquisitions. The initial model was based on the legacy Isotropic Pre-Stack Depth Migration (PSDM) velocity model, built with water velocity analysis, isotropic PSDM velocity model and anisotropy estimation. Sediment velocity update was conducted in three steps: 1st Tilted Transverse Isotropy (TTI) Tomographic Iteration, 2nd TTI Tomographic iteration and FWI. The intra-salt velocity was updated using two tomographic iterations. To resolve the velocity of the sediments below overhangs, a nonlinear tomography inversion was performed. Once the intra-salt and sediment bellow overhangs velocity were settled, the regional base of salt was interpreted followed by the Pre-salt velocity update.

Methodology

An initial examination of the lithology and Vp logs in the salt section of the two wells in the structure and other wells in a similar nearby structure was performed. To understand the effect of the different salt minerals, in the velocity model, a statistical analysis of salt composition and its velocity was performed. A study over the interval velocity model was conducted, either by simple visual confrontation with the seismic amplitude image or by extraction, analysis and correlation of maps inside the salt layer, such as isopach map and interval velocity average maps. This made it possible to define an attribute, used as a conditioner, to accurately distribute, spatially and vertically, the stratifications inside the salt layer of the interval velocity model. Stratifications were inserted by application of some mathematical operations to modify the interval velocity volume and honor the lithology and Vp from the wells. A smooth over the stratified model was required to reduce the spatial contrast created by the stratifications avoiding problems in the time-depth conversion of the final data. Although the stratification process has corrected some depth positioning, it introduced misties in some wells. A Final step of calibration of stratified smoothed model with well velocities was conducted. Calibration is performed using kriging with external drift over the time domain average velocity, where average velocity from wells is the hard data and the stratified smooth model is the drift.

Results

The analysis of well logs identified important heterogeneities (salt-stratifications) in the wells, especially in those below minibasins, where the isopach of salt tends to be relatively smaller. By comparing these logs with the processing velocity model log, it was noticed that these salt stratifications were not represented (Figure 1). Lithologic analysis of salt identified halite as the dominant mineral of the distribution (~86%), followed by anhydrite (~10%), carbonates (~2%), carnallite (~2%) and other (less than 1%). As anhydrite has a higher velocity range than halite velocity (Maul et al., 2018), the absence of these stratifications in the velocity model causes a significant decrease in the compressional velocity. Including those stratifications in the model should be enough to deepen the reservoir.

A comparison between the seismic amplitude image with the interval velocity model showed that stratified events present in the amplitude section in specific regions were not represented in the velocity model (Figure 2). Even being observed that there was a subtle tendency of increase in the interval velocity, in the areas where the amplitude data shows stratifications, there are no details of them in the corresponding velocity section, probably not accounting for properly imaging and positioning. it was verified that the average interval velocity ranged, approximately, from 4570 m/s to 4630 m/s, indicating that tomography did not resolve properly the high velocity salts stratifications and imposed a velocity lower than the reality of the present geological features. The methodology to insert the high velocity stratifications inside the salt layer (Gobatto et al., 2016; Maul et al., 2018; Dias et al., 2019; Maul, 2020; Maul et al., 2021), conditioned by a seismic volume was applied, to correct the depth positioning in the problematic area.

It was noticed a strong correlation between relatively thinner thickness salt and HVS occurrences,

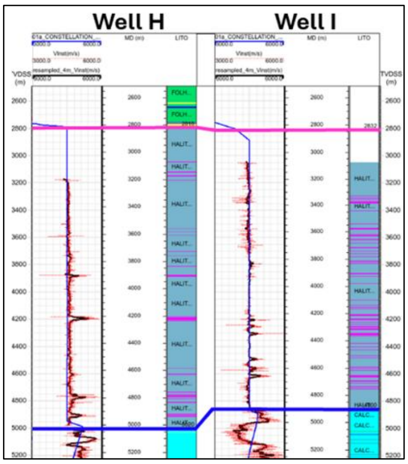

Figure 1: Analysis of Vp and lithology well logs and comparison with extracted Vp log from velocity model. In red, Instantaneous Vp; In black, Instantaneous Vp, resampled to 4m; In blue, Vp extracted from velocity model.

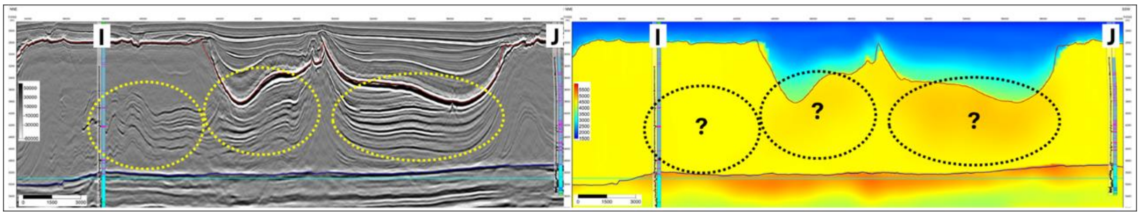

Figure 2: Seismic data on the left and velocity model on the right. Dashed ellipses show stratified salt not represented on the velocity model.

The interval velocity volume was modified by inserting those high velocity layers, increasing the average interval velocity inside the salt layer and generating a strong lateral velocity contrast, solved by the application of a smooth filter. Figure 3 illustrates the result of the full stratification process in the section that connects the two wells in the problematic area. A few spill points were created, isolating two structural highs, each one containing one of the wells.

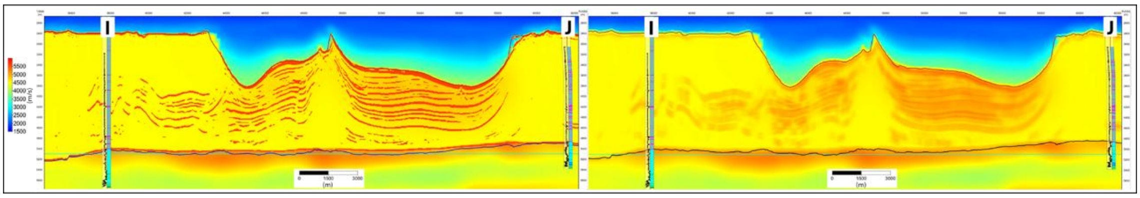

Figure 3: Results of insertion of stratified high velocity layers. left - Stratified Interval Velocity Model, with HVS layers and right - Final Smoothed Stratified Interval Velocity Model

The final calibration of wells velocities adjusted the average velocity of the model in the position of the wells and, where there were no wells, slightly decreased the average velocity model, using the correlation trend between wells and model velocities. Although the adjustments performed by kriging in the wells showed good results, in areas with no wells, a decrease in the calibrated velocity pushed the base of salt above the oil-water contact, reconnecting the wells and removing the spill points created by model stratification process. To circumvent this issue, pseudo wells were introduced, strategically positioned in the spill points areas created by the stratification, to guarantee the increase in the average velocity obtained by the stratification process. Figure 4 shows the results of calibration before and after the incorporation of pseudo wells information.

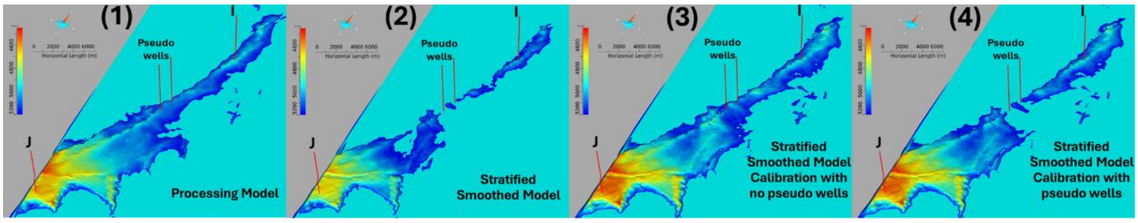

Figure 4: Final depth conversions of top reservoir: (1) original processed data – structure connected; (2) smoothed stratified model – spill points created; (3) calibration of smoothed stratified velocity model without pseudo wells - structure reconected; (4) final calibration of smoothed stratified velocity model introducing pseudo wells – spill points statement.

Conclusions

Incorporation of complex geological features in the velocity models is not always a simple task to accomplish. In the case of Santos Basin's evaporitic layer, although seismic and well data show that it has internal stratifications, velocity models from tomographic iterations consider it as a relatively homogeneous and isotropic layer for the purposes of imaging. The methodology for insertion of heterogeneities into velocity models was successfully applied to establish a precise distribution of evaporites interval velocities in the model which, supported by analysis of well data, provided greater robustness to the results.

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