Modelling intra-salt layers when building velocity models for depth migration. Examples of the Santos Basins, Brazilian offshore

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Summary

Building seismic velocity models honouring complexities evident from seismic data is fundamental to generate inputs for several applications in seismic modeling and imaging. This is particularly important for complex areas, such as the Pre-Salt section of Santos Basin, in the Brazilian offshore.

We present a methodology to build velocity models incorporating the geological features identified in legacy seismic data for this basin. Of particular interest is, the internal stratification within the salt section. To characterize a geological layer we propose the use of model-based impedance that combines the geological knowledge from wells and seismic interpretations using rock property relationships.

The results are shown in both gathers and stacked migrated sections with improvements in the flattening and the focusing of target reflectors. This approach can also be extended to generate an input velocity model for FWI migration process.

Introduction

The Brazilian oil & gas industry is undergoing a huge increase in activities since the Pre-Salt reservoir province has been discoveried in 2007, and subsequently, developed. Seismic imaging technology followed on and moved towards this new and challenging target, pointing to a new big issue: how to deal with the evaporitic salt section, commonly just called as “salt”. Complex stratifications within the salt section and huge variations in salt thickness and topography contribute to create an environment where standart seismic imaging techniques are no longer applicable. This has created research activities devoted to improve the existing seismic capabilities, both in the industry and the academia. The results when applying this approach have some impact on several studies, ranging from seismic modelling and processing to reservoir simulation and well stability.

To build velocity models better representing areas with great geological complexity is one of the biggest challenges related to seismic migration process. Jones & Davidson (2014) have presented and discussed many examples in which enhanced velocity models increase significantly the quality of seismic images around, under and inside salt bodies.

Wang et *al*. (2017) mentioned that a carefully designed seismic acquisition and a good migration strategy combined with a good velocity model increases the chances to preserve the seismic signal under salt layers.

This paper describes an approach for building velocity models consonant with the local geology (such as the internal stratifications within the salt section) combining seismic attributes and facies analysis. Also mentioned are the applications in seismic processing (Fonseca et *al.*, 2018).

The results can also be useful for several other applications such as uncertainty analysis regarding both depth positioning and signal quality, seismic acquisition design, inversion studies, geomechanical simulation studies, and well drilling safety. We will focus on the quantitative seismic inversion approach and its benefits for seismic reprocessing, as described by Gobatto et *al.* (2016).

Methodology, Applications and Examples

The method was first presented by Maul et *al.* (2015) and then explored how to insert the straitifications using amplitude response inside the salt section and its usage for illumination studies. González et *al.* (2016) presented the workflow stablished by Maul *et al.*, (2016) in order to model any salt stratification for Pre-Salt projects (figure 1).

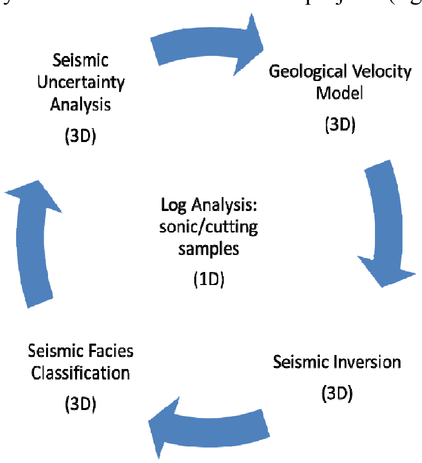

Figure 1: Proposed workflow to generate a more realistic seismic velocity model (*adpated from Maul et al., 2016 in González et al., 2016).*

Meneguim et *al.* (2015) have discussed the benefits of using acoustic inversion and facies classification to model stratifications inside the salt section in Santos Basin.

However, only appraisal wells had the required elastic logs necessary for the inversion process. To overcome this very common limitation, Barros et *al.* (2017) presented a method to fill these well log gaps in the salt section allowing a more controlled seismic inversion.

Teixeira et *al.* (2017) illustrated the benefits of inserting the stratification using seismic inversion and seismic facies classification to generate calibrated information for geomechanical simulations and rock drilling forecast in terms operational safety. These authors have presented that the compressional velocity for evaporate rocks have a strong relation with the acoustic impedance, proposing cubic equations to relate them. Therefore we generate interval velocities from model-based acoustic inversions for salt rocks. Additionaly, this concept could be extended for the carbonate rocks. Figure 2 illustrates the relation between compressional velocity and acoustic impedance from well logs data for the salt section.

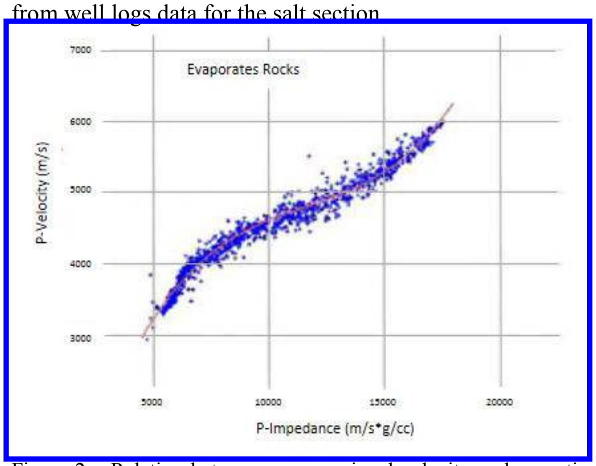

Figure 2: Relation between compressional velocity and acoustic impedance for Evaporates Rocks *(adpated from Fonseca et al., 2018).*

The relation illustrated in figure 2 was applied on acoustic impedance from sesimc inversion in order to generate a P-Velocity model to be used for migration process as shown in figure 3. In this paper we not are intent on discussing other known problems regarding migration process concerning both the Pre-Salt and the Post-Salt velocity behavior, only the more feasible velocity for the salt section.

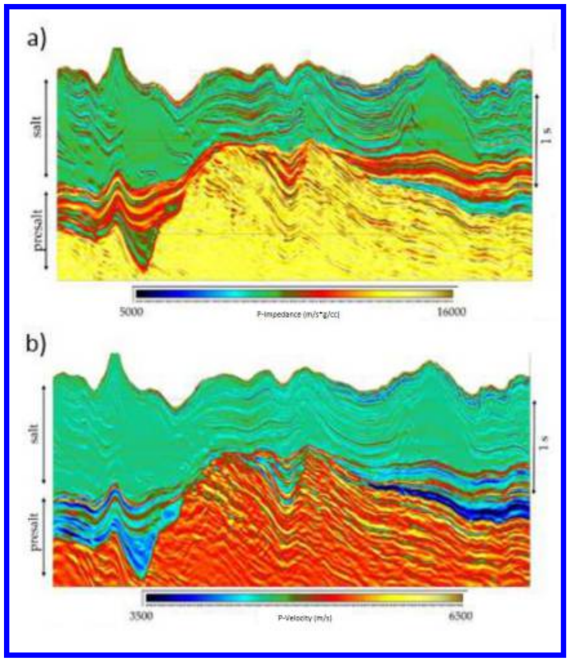

Figure 3: (a) P-Impedance of the Salt Section and the Pre-Salt Section and (b) generated compressional velocity after applying the cross-plot rules on the P-impedance volumes. *(adpated from Fonseca et al., 2018).*

Gobatto *et al.* (2016) and Fonseca *et al.* (2018) had proved the benefits when using the salt stratification for migration purposes. Through figure 4, the last authors showed the enhancements of resolution when including the stratified salt model into the initial velocity model to perform seismic tomography updates for migration process.

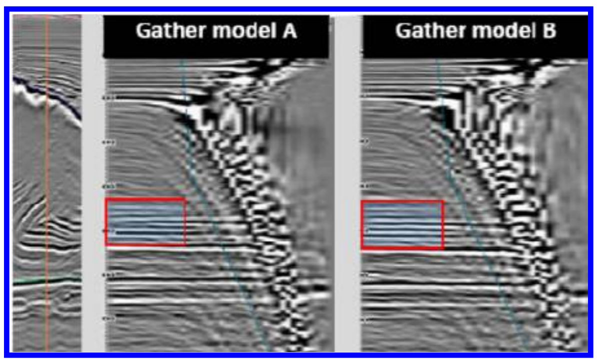

Figure 4: Subset of a migrated amplitude section. The orange line represents the trace whose depth migrated gathers are displayed. The letters refer to the velocity model: (A) Previous velocity model from tomography and (B) updated velocity model with the salt region modelled through impedance. The red boxes highlight stratification events, demonstrating an enhancement of such events within the salt section. (Adapted from Fonseca et *al.*, 2017 *in* Fonseca et *al.*, 2018).

Finally, the figure 5 demonstrates the obtained gain on an amplitude seismic sections with better focusing in the base of salt which is mapped as the top of the first Pre-Salt reservoir in many projects, and in the underlying formation**.**

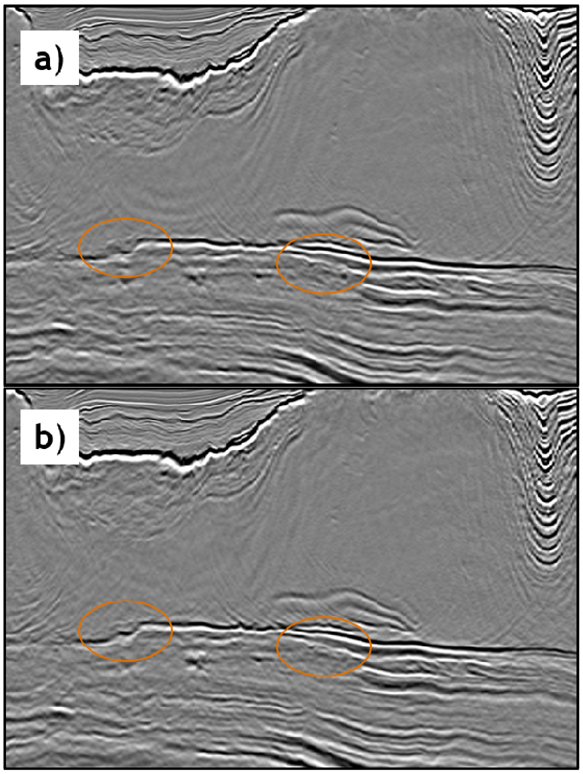

Figure 5: Seismic amplitude migrated with different velocity models: (a) tomography-only and (b) salt inversion. The orange ellipses highlight the base of salt and the reflector continuity.

Conclusions

Studying the Pre-Salt reservoirs is a complex task, not only because of the type of rocks, but also because of the heterogeneity of the overburden and the structural features. The presented workflow for building seismic velocity models attemps to improve the model building better representing the geological characteristics of the salt section, giving more realistic inputs and facilitating interpretations as well as any other data analysis.

As described in this work, geological features must be considered when building velocity models for seismic processing purposes. The salt section, in particular, must be represented as an inhomogeneous section instead of an almost constant P-velocity section as found after the so-called salt-flooding processing. Even after a tomogaphy updating process, when the velocity is no longer almost constant, it presents several artifacts or “bull-eyes” still not honoring the geology. In contrast our workflow to represent salt heterogeneities is heavily supported by rock property analysis from well and seismic data.

We also suggest that geological-constrained velocity models built using the presented workflow are good initial models for the Full Waveform Inversion (FWI) method since they improve the convergence and prevent from the local minima during the FWI process.

We also advocate that the applications of these models have shown more consistent results, enabling better understandings of seismic responses and better reservoir characterization. Several other areas such as illumination studies, inversion studies, facies classifications, depth uncertainties, geomechanics and safety operational aspects in drilling process have also benefited from this metodology.

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