Dealing with Evaporitic Salts Section in Santos Basin during Geological Seismic Velocity Construction

Josué S. Fonseca* (Petrobras), Fernanda Gobatto (Petrobras), João Boechat (Petrobras), Alexandre Maul (Petrobras), Thiago Yamamoto (Petrobras), Eliane Born (Petrobras), Leonardo Teixeira (Petrobras) & María González (Paradigm)

This paper was prepared for presentation during the 15th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 31 July to 3 August, 2017.

Abstract

Honoring depth information provided by wells is essential when building seismic velocity models. This concept can extend also to honor the information provided by interpretations, log well data, seismic attributes, conceptual geological models.

From these assumptions it is reasonable to create velocity fields reflecting subsurface geology. Therefore the model could be built extrapolating within the interest area all the available information following the previous described premises.

A good seismic velocity model could enhance several studies/applications such as: seismic illumination, seismic processing, tomography, anisotropy, depth and lateral positioning, uncertainty analysis, quality of amplitude. Even other areas like geomechanics and well drilling projects can improve their results using these realistic velocity models, observing the existing geology as input.

In this work we present a specific management of velocities within evaporitic salt section and the realistic premises involving the geological velocity model construction.

Introduction

To characterize any kind of reservoir good quality seismic images are essential. Besides, accurate depth estimation is mandatory for any seismic usage. Hence, it is necessary to design robust seismic acquisition as well as a good strategy regarding processing. Both must be focused on the interest reservoir.

Getting inside at each step of subsurface image building, it is notable that the used velocity model plays a big role for the final result.

In order to have a better comprehension of the reservoirs through seismic we must have a reliable model about what is above them, particularly the P-Wave velocities. This could be partially reached with mathematical concepts/approximations as tomography, for instance.

However, the majority of velocity models generated only by tomography do not properly represent geological features as demonstrated in Falcão et al. (2014). Incorporating rock knowledge above the reservoir, in terms of velocity models, has demonstrated great potential to solve this matter. When used in reprocessing, improves the seismic image quality, as shown in Gobatto et al. (2016). Besides this, for illumination studies such as Jardim et al. (2014), Maul et al. (2015) and Jardim et al. (2015) have demonstrated better results.

Excellent examples of velocity fields including geology have appeared when an effort was made to create better images of pre-salt reservoirs in Santos Basin. Maul et al. (2016) demonstrated how to incorporate stratifications on evaporitic salts layer and several usage for this kind of approach.

The main objective of this work is to present how we build velocity models in some areas of Santos Basin using geology as constrains. This knowledge is derived from previous seismic image constructed using available dataset. The key aspect to be focused is the velocities determination inside evaporitic salts section including its observed stratification. Beyond this we will explore how to manage honoring well depths, information from logs, seismic attributes, adjustment of depth migrated gathers and defining velocity values to fill information gaps.

Method

In González *et al*. (2016) it is proposed iterative workflows integration to generate more realistic geological seismic velocity models (figure 1). Therefore, as a new image is built, it is possible to use it to update and refine the velocity model enhancing seismic image until the objective resolution and quality is good enough.

A geological reservoir model is always supported with well data: logs, cores and plugs. The same methodology should be applied when building geological velocity models. A detailed well data analysis for salt section was first described by Amaral *et al*. (2015). After that, we enter in the loop of assembling the velocity models that honor both geology and seismic.

The first presented strategy to incorporate stratification within evaporitic salts layer uses amplitudes variation to match different kinds of salt (Oliveira *et al*., 2015). However, only amplitude usage to discriminate changes in thin stratification may be a pitfall due to side lobes from other reflections. As per Meneguim *et al*. (2015), an alternative way to enhance the thin stratification recognition considers seismic model based acoustic inversion.

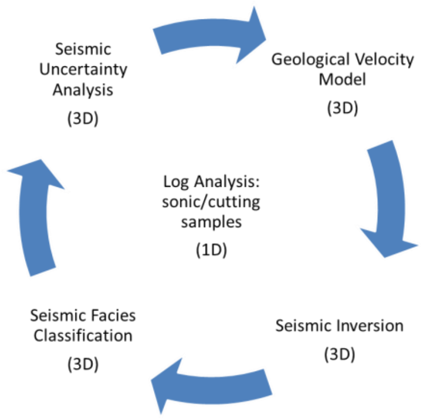

Figure 1: The proposed workflow to generate a more realistic geological seismic velocity model (adapted from Maul *et al*., 2016 *in* González *et al*., 2016).

Getting inversion results, it is necessary to create a function to transform AI (acoustic impedance) in feasible P-wave velocity values. Therefore we can use well logs to cross-plot the sonic velocity against AI calculated from sonic and density, as shown in figure 2.

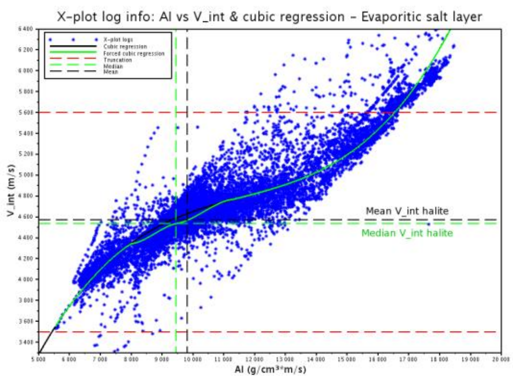

Figure 2: Well logs X-plot within evaporitic salts layer of one specified field in Santos Basin. It is made to determine a third degree polynomial regression correlating AI and P-Wave velocity.

As we can see in figure 2, the green and black dashed straight lines are calculated reference values from well analysis. Black is the mean correspondence and green median one. The red dashed straight line is the used truncation values to construct the velocity model. The black solid curve is the regression itself, and the green solid curve has an adjustment trying to match AI median value to halite velocity median value which represents more than 80% within evaporitic salts section.

Finally, the first geological velocity model representing stratification within evaporitic salts section is built. Then, a new seismic data migration is performed enabling evaluation of new seismic images.

The referred seismic analysis considers the integration of all available information. The first aspect to take into account in this integrated analysis is the gathers alignment. The second one corresponds to depth position observed in drilled wells. Several velocity model versions are created in order to obtain the most appropriated seismic response in terms of quality and depth positioning.

Results

We believe the stratification incorporation within evaporitic salts section using velocity models for pre-salt fields in Santos Basin should be a standard input for seismic depth migration.

Besides seismic processing, this kind of model could be used in several other areas, eg: geomechanics, seismic acquisition illumination studies, uncertainties in terms of amplitude quality, lateral and depth positioning, well drilling projects, etc.

A Santos Basin particular area is shown in figure 3. The used velocity model to build the seismic image does not represent any stratification as noticed in seismic amplitude.

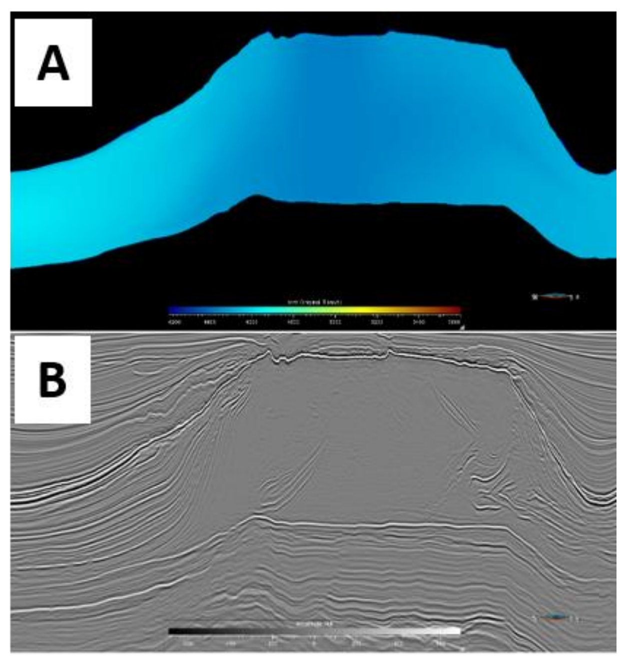

Figure 3: (A) Velocity from tomography not considering any stratification within salt layer (B) Amplitude seismic section showing stratification within salt layer. It is important to mention this velocity was used to generate the amplitude image.

To assemble a more realistic geological velocity model considering the needed stratification as described in our methodology, we performed an amplitude and inversion analysis showing results to be verified from figure 4.

Figure 4A represents acoustic inversion performed in amplitude data (figure 3B). After that, velocity values from inversion were calculated using the equations described in figure 2.

Figures 4B and 4C show first and last tested velocity models to migrate data, respectively. Some issues regarding the transition between velocity models 4B to 4C are relevant and will be addressed once several test models were created.

Here, we will discuss the subject concerning the regression to be used to calculate velocity from AI. The first velocity model we were able to test migration is represented in figure 4B. It was built simply by applying demonstrated black regression. The depth migrated gathers showed reasonably flat events within evaporitic salts section. However, when compared with well depth values, we noticed that velocities must be lower than the used one. That was the motivation to change our function between AI and P-Wave velocity, using the green curve instead the black one. Even though the well depths were honored, events in gathers were no more flat, suggesting velocities were lower than needed.

As the first used criteria is to get alignments over gathers, we stated to keep black solid line regression. To fit well depths was adopted another strategy lowering velocities where no stratification events were presented within evaporitic salts section, especially in dome and/or diapiric domains. In these areas it is suggested the salts were mobilized mixing all the moveable salts: halite, carnalite, tachydrite. Justen (2014) demonstrated lower velocity in salt section reflects more than only halite velocity (4500m/s) reducing in average the measured velocities. For that reason regions were generated inside evaporitic salt section corresponding to domes/diapirs.

In seismic amplitude data, domes in evaporitic salts section are easily identified by the absence of reflections (see figure 3B). Then those regions could be established through energy seismic attributes, and lower velocities would be assigned for them, as demonstrated in figure 4C.

Getting the appropriated regions (domes/diapirs) the problem relies on what is the velocity value to be considered for those domains. Any values (from 4400 to 4500 m/s) are supposed to deal with alignment on gathers, affecting only depth. Figure 5 presents seismic migrated sections varying built velocity models. Figure 5A represents the amplitude image using original tomography model (previous processing). Figure 5B represents the same section considering the modeled velocity built in described workflow.

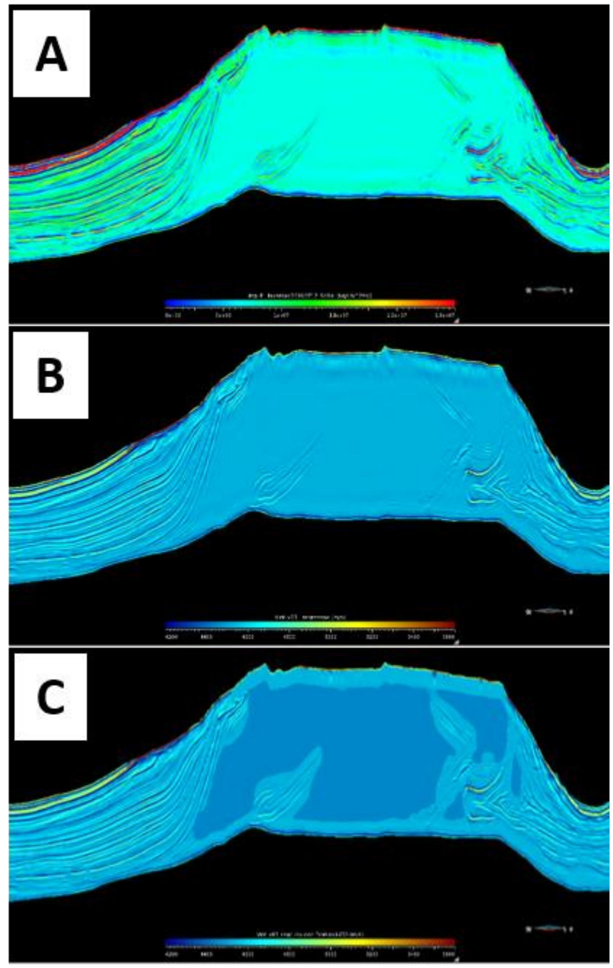

Figure 4: (A) Acoustic impedance derived from inversion of amplitude seismic data; (B) Calculated velocity using inversion and regression curve; (C) Adapted velocity to adjust wells with migrations.

The gather displayed in figure 5 was chosen to demonstrate domes and stratifications together for better comparison. Both models seem to return good seismic image regarding gather alignment and depth position. Anyhow, the highlighted area demonstrated a gain in amplitude response when using geological velocity model with minimum tomography effort to obtain the gather alignment.

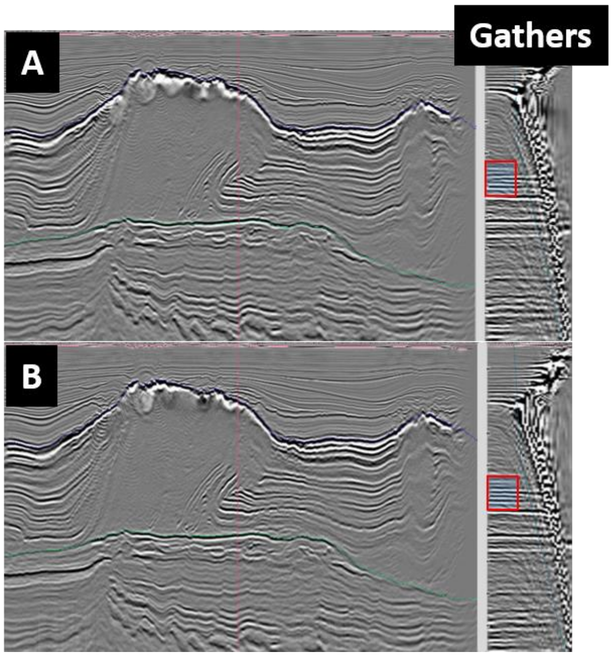

Figure 5: Same stacked amplitude section with different velocity models as input to migration. Red line on section represent the trace depth migrated gathers on section side. The letters refer to the used velocity model:
(A) Original velocity from tomography shown in figure 3A;
(B) Geological velocity chosen as shown in figure 4C.
The red boxes on gathers highlight stratification events, demonstrating recuperation and enhancement of events.

Depending on the project, this domes areas can be created with another approach. In Carvalho (2012) was demonstrated the mapping of cycles within evaporitic salts section. Therefore, if the area has this kind of information (the mapping of internal cycles) could be possible to change velocity values inside the domes/diapirs region.

In the end of this workflow, was created just one deterministic geological velocity model to recreate the seismic image. Although, with acoustic inversion would be possible to simulate seismic facies using probabilistic density functions from well data as described in Meneguim *et al*. (2015), creating velocity models to perform seismic uncertainty regarding depth positioning.

Other approach for this model construction could be verified in Borges *et al*. (2015). These authors suggested a trend to increase/decrease the velocity models in complex areas.

Conclusions

Geological velocity models have been showing improvement in final products derived from several seismic processes where they are necessary as input. However, we have to remember, it is still just a model from indirect measures and, by definition it is wrong or at least naive. Hence we will always have space to develop models reflecting more and more the reality.

In case of Santos Basin, stratification incorporation within evaporitic salts section is just the first step to improve seismic image and depth estimation of pre-salt reservoirs. Further we need to dedicate studies to model velocities honoring geology on post-salt layer, as well as anisotropic considerations.

To incorporate more geology, information is required. Therefore, to determinate velocity values above reservoir, well data logs also should be acquired on previous layers before reach the objective. For instance, evaporitic salts layer need more logs information.

Converging to a geological velocity model and the construction of a good seismic image that honor all available information has been possible due to migration tests on data while assembling the model.

Acknowledgments

The authors would like to express their gratitude to Petrobras to give all needed support to this study as well as to allow its publication.

References

Amaral, P. J. T., A. R. Maul, L. Falcão, N. M. S. M. Cruz, M. A. González, and G. González (2015), Estudo estatístico da velocidade dos sais na camada evaporítica na Bacia de Santos. 14th International Congress of the Brazilian Geophysical Society, 666–669.

Borges, F., D. Apoluceno, H. Selbach, A. Maul, and G. Lima (2015), Thickness-based approach for evaporites seismic velocities in Campos Basin. 14th International Congress of the Brazilian Geophysical Society & EXPOGEF, 808–810.

Carvalho, R.S. (2012). Tectônica Intra-Sal: Estudo na Região do Alto Externo, Bacia de Santos. Rio de Janeiro - RJ Petrobras - Internal Publication.

Falcão, L., Maul, A.R., Novellino, V.S. & Gonzalez, G. (2014) – Construção de Modelos Geológicos de Velocidades. Aplicações em: Estudos de Iluminação, Reprocessamento e Geração de Cenários de Reservatórios. XIV SIMGEF (Simpósio de Geofísica da Petrobras), Vitória – ES – Brasil – Internal Publication

Gobatto, F., Maul, A., Falcão, L., Teixeira, L., Boechat, J.B., González, M. & González, G. (2016). Refining Velocity Model within the Salt Section in Santos Basin: an Innovative Workflow to include the Existing Stratification and its Considerations. (SEG – Society of Exploration Geophysicist – 2016) – Dallas – TX, USA.

González, M., F. Gobatto, A. Maul, L. Falcão, G. González, L. Oliveira, T. Meneguim, and P. J. Amaral (2016), Proposed workflow to incorporate stratification within salt section using velocity and seismic attributes. 78th Annual International Conference and Exhibition, EAGE, Extended Abstracts.

Jardim, F. Maul, A.R., Falcão, L. & Gonzalez, G. (2014) – Análise de Incertezas de Reservatórios da Seção Pré-Sal utilizando Estudo de Iluminação (Hit-Maps). XIV SIMGEF (Simpósio de Geofísica da Petrobras), Vitória – ES – Brasil - Internal Publication.

Jardim, F., Maul, A., Falcão, L., & González, G. (2015) Estimating Amplitude Uncertainties Through Illumination Studies for a Pre-Salt Reservoir. 14th International Congress of the Brazilian Geophysical Society 2015 – Rio de Janeiro – RJ.

Justen, J.C.R. (2014) - Análise das propriedades elásticas de rochas e minerais evaporíticos. Dissertação de Mestrado do Departamento de Engenharia Civil: PUC-Rio – Rio de Janeiro

Maul, A.R., Jardim, J.S., Falcão, L. & Gonzalez, G. (2015) – Observing Amplitude Uncertainties for a Pre-salt Reservoirs Using Illumination Study (Hit-maps). 77th EAGE Conference and Exhibition 2015 in Madrid, Spain.

Maul, A., L. Falcão, F. Gobatto, V. Novellino, F. Jardim, L. Oliveira, T. Meneguim, P. J. Amaral, F. Borges, L. Teixeira, R. C. Monteiro, G. González, and M. González (2016), Incorporação de estratificações dentro da seção evaporítica utilizando velocidades e atributos sísmicos: IGP-152, Informe Geofísico da Petrobras – Internal Publication.

Meneguim, T. B., S. C. Mendes, A. R. Maul, L. F. Fernandes, M. G. Farias, and G. Gonzalez (2015), Combining seismic facies analysis and well information to guide new interval velocity models for a pre-salt study, Santos Basin, Brazil. 14th International Congress of the Brazilian Geophysical Society & EXPOGEF, 1365–1368.

Oliveira, L., L. Falcão, A. Maul, J. Rosseto, M. González, and G. González (2015), Geological velocity approach in order to obtain a detailed velocity model for the evaporitic section, Santos Basin. 14th International Congress of the Brazilian Geophysical Society & EXPOGEF, 1374–1377.