Gross-Rock Volume Uncertainties Based on the Integration of Velocity Model and Seismic Resolution.

Mario Paes[1],*, Carlos Pereira[1], Alexandre Maul[1], Talles Meneguim[1], Vinicius Pinto[2], María González[2], Gerardo González[2], Randi Sundt Meyer[2] & Susanna Lervik Furland[2] (1 – Petrobras, 2 – Emerson E&P Software)

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Abstract

The reservoir characterization for the Pre-Salt reservoirs in Santos Basin, Brazil, currently represents a major challenge to the subsurface models. In the development stages, the absence of well information is the main cause of this aspect. Added to this fact, we also consider the quality and resolution support related to the seismic data to generate depth uncertainties regarding velocity modelling as a big matter to take into account. To exemplify how the analysis and quantification of such uncertainties affect the estimation of gross-rock volume, we propose two different ways of building the velocity models to perform depth positioning. In the first scenario, we adopted a constant velocity of 4,500 m/s for the entire salt section. The second scenario considers variability regarding the internal velocities of salt stratifications when building the velocity model. We generated a set of 300 realizations for each scenario, accounting the uncertainties for the structural modelling/positioning. We based our analysis considering the Gross Rock Volume (GRV) differences. The differences between the pessimistic and optimistic realizations were close to 1.6% and 2%, for scenarios 1 and 2, respectively. They represent considerable GRV volume variation of approximately 3.10^9 m^3. Additional parameters such as Net-to-Gross (NTG), porosity and oil saturation, influencing oil reserve calculations, will be considered in future uncertainty studies.

Introduction

The Santos Basin in Brazil, with Pre-Salt reservoirs, is a successful play regarding exploration and development stages. Despite the huge oil accumulations, the post depositional characteristics classify these reservoirs as production frontiers. The main challenges in production are related to the complexity of both the structure and faciology of the microbial carbonates. The lack of well information is one of the main problems as well as the quality and resolution of the seismic data, which generate depth uncertainties regarding velocity modelling.

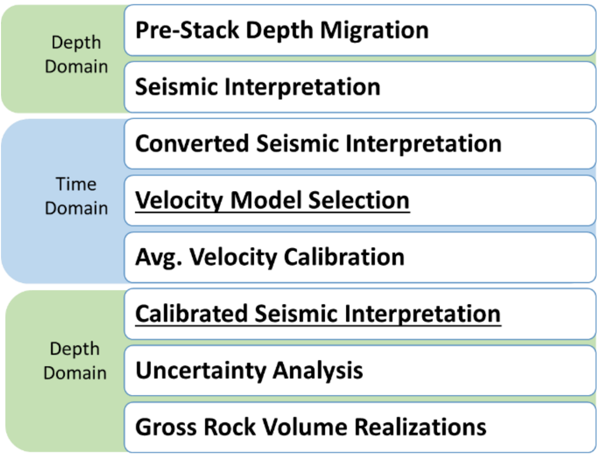
Several efforts have been made to understand the impacts of such uncertainties as early as possible in the structural modelling. This can be done by analyzing the uncertainty parameters in the velocity modelling, as described by Maul *et al.* (2018b), and in the seismic interpretations (Leahy and Skorstad, 2013; Leahy *et al.*, 2014; Pinto *et al.*, 2017). Even small variations can dramatically affect the top reservoir surface shape and position. Depending on the uncertainty parameters, hydrocarbon reservoir volumes may then be added, or reduced, to the initial GRV. Therefore, it can mask the project economics leading to wrong decisions.

Different approaches were applied to build velocity models which aims to analyze and quantify the impact of the considered uncertainty parameters in the structural model. The first scenario uses a constant velocity of 4,500 m/s for the entire salt section. The second scenario considers velocity variations imposed by the stratified salts to build the velocity model. Both models were calibrated using well markers. Due to the limited seismic resolution the ambiguities present at the position of the top reservoir were analyzed. A set of 300 realizations for each scenario was created to account for the uncertainties in the structural model. The 600 realizations were then analyzed based on their Gross Rock Volume (GRV), enclosed by the top reservoir surface, and a bottom surface represented by the Oil-Water Contact (OWC). Finally, the presented methodology can guide geoscientists through the analysis of different velocity models, as well as several sets of seismic interpretations, to evaluate the impact of such uncertainties may have on E&P projects.

Method

Lateral velocity changes may affect the seismic image due to the complexity of the salt section (Ji *et al.*, 2011; Jones and Davison, 2014, Fonseca *et al.*, 2018, Maul *et al.*, 2018b). Therefore, Pre-Stack Depth Migration (PSDM) is mandatory to build the Pre-Salt seismic images in a more reliable way. This type of migration allows best positioning of the structures for both vertical and lateral aspects although without an accurate well calibration. Deviations between well markers and interpreted surfaces of approximately 1% are commonly found. This misfit analysis complements the reservoir characterization (Roque *et al.*, 2017). Additionally, the seismic interpretation is always a tricky procedure, due to the inherent limited seismic resolution, low signal-to-noise ratio and human biases.

The methodology presented in this work comprises the analysis of uncertainties on GRV due to variations in velocity modelling scenarios and seismic interpretation, as following:



The underlined steps refer to where the uncertainty parameters were identified and handled. The original velocity model from tomography was used to convert the seismic data and interpretations from depth to time domain. Subsequently, two scenarios of velocity for the salt section were built to perform the well calibration and conversion back from time to depth.

Both scenarios were updated using inversion tomography iterations, evaluating the gather alignment in the Post-Salt section, as described by Maul *et al.*, 2018a. For Scenario 1, the salt section presents a constant velocity of 4,500 m/s. This is a common workflow for seismic migration of Pre-Salt reservoir projects (Figure 1 - A).

On the other hand, the presence of different evaporite minerals, such as halite, anhydrite, carnallite, tachyhydrite and sylvite has been observed when analyzing samples from wells (Amaral et al., 2015; Barros et al., 2017). Thus, a stratified salt model following the idea presented by Meneguim *et al.* (2015) was built, using acoustic inversion and Bayesian facies classification to incorporate the salt stratifications in a 3D model. This approach helped to build the second scenario (Figure 1 - B). Figure 1 - C shows the probability density functions (PDF) and average values of velocity for each mineral in the salt section to be considered in the model.

After the well-to-seismic-tie, Time-Depth (TD) relations for each well were created. These relations were then used to calibrate the average velocity model for both scenarios. In the regions away from the wells, an external drift kriging technique was used, considering the average velocity as soft data (both scenarios), and the tied well velocity (markers) as hard data. Finally, the seismic data and interpretations from time to depth were converted, ensuring that the interpretations matched the well markers.

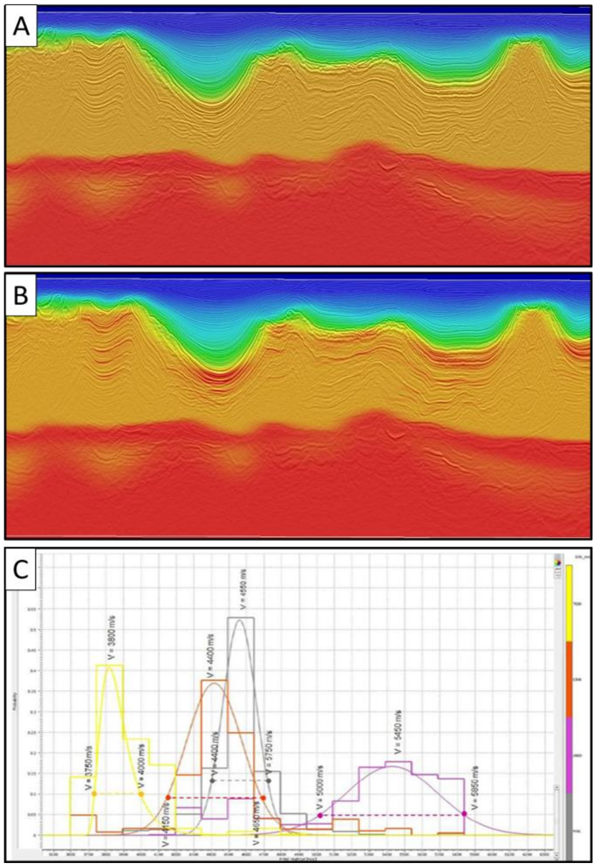


Figure 1: Differences in the velocity models from scenarios 1 **(A)** and 2 **(B)**. Scenario 1 uses the tomographic velocity, and Scenario 2 incorporates the salt layers inside the evaporitic section. **(C)** PDF of salt velocities from well data. Extracted from Meneguim *et al.* (2015).

To obtain the two GRV scenarios, the top reservoir surface was converted using both calibrated velocity models (Scenarios 1 and 2, respectively). The bottom surface has been kept unchanged. Afterwards, for each top surface were generated stochastic Monte Carlo simulations. In each realization, the resultant map is the original surface added by a Gaussian residual map, produced in the simulation process. The limit of the seismic resolution was considered as an envelope, surrounding the top reservoir surface, for the depth variation range. This seismic envelope is intended to be a volume enclosing the top reservoir surface, where the interpreter cannot resolve its correct position (Pinto *et al.* (2017)). This envelope is built considering the resolution limits introduced by Widess (1973), by combining the dominant frequency and interval velocity attributes into one map. Later, this map was weighted by the RMS amplitude map to account for low signal-to-noise ratio regions affecting the resolution quality (Figure 2 - A). This map can be thought as an uncertainty map providing somehow the level of confidence on the interpretation, based on the adopted criteria.

Using this approach, the values found for the seismic envelope ranged from 70 m (35 m up and below the top surface) to 200 m (100 m up and below the top surface). Therefore, the new surface is probabilistically located, according to the seismic resolution. The assumption of the envelope is located equally distant above and below from the surface relies on the fact that there is no previous hypothesis about where the top surface could be initially located. Additional information, such as alternative interpretations, data from different methodologies, well log data, core samples, and others, as well as many assumptions could be used and other bias can be introduced.

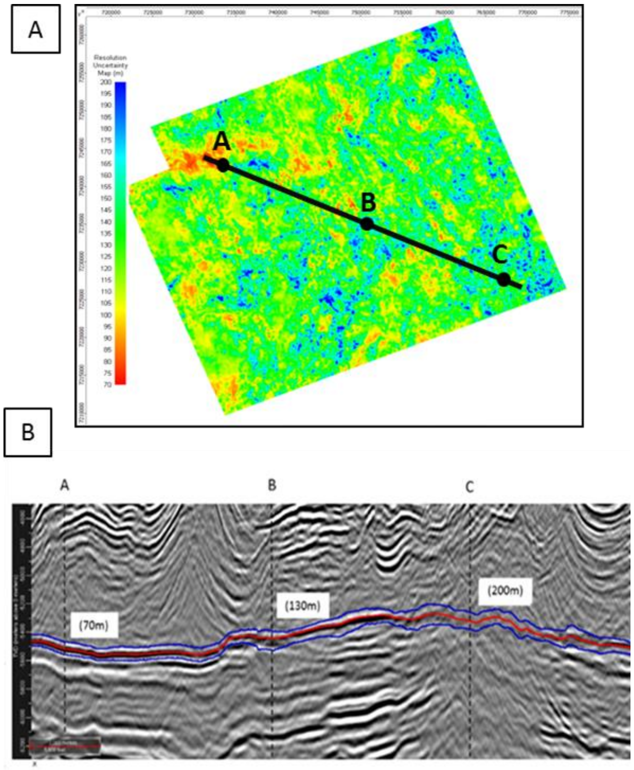


Figure 2: (A) Uncertainty map utilized in the stochastic simulations. **(B)** Seismic section with top reservoir (red) and the uncertainty envelope (blue). The vertical range of the uncertainty envelope is shown for wells A, B and C.

Results, Conclusions and Future Works

Stochastic simulations using Monte Carlo method were performed to generate two subsets with 300 realizations for each velocity model scenario. Each realization represents a possibility for the top reservoir surface. Gaussian residuals, generated in the simulation runs, were added to the surface to achieve the realization surface. The residual follows the parameterized variogram and the uncertainty map. All the 600 top surfaces produced by the simulations were calibrated with the well markers. The misfit at well locations driven by the calibration algorithm was set to zero. At other locations, the surfaces were set free to move with respect to the velocity modifications in each scenario, and according to the seismic uncertainties shown in Figure 2 - A and 2 - B.

Figure 3 shows a subset with 20 realizations for each scenario, illustrating the character of the top reservoir surface along the simulations. The GRV was considered as the response parameter to classify the realizations. By analyzing all realizations, it is possible to observe and quantify the pessimistic (lower GRV value) and optimistic (higher GRV value) realizations for Scenario 1 and 2 (Figure 4). The differences between the pessimistic and optimistic realizations were close to 1.6 % and 2 %, for Scenario 1 and 2, respectively. These differences represent GRV volumes variation of approximately 3.10^9 m^3. To illustrate this amount, the reservoir covers an area of approximately 1,000 km^2, with an oil column that varies between 300 m and 400 m, for instance.

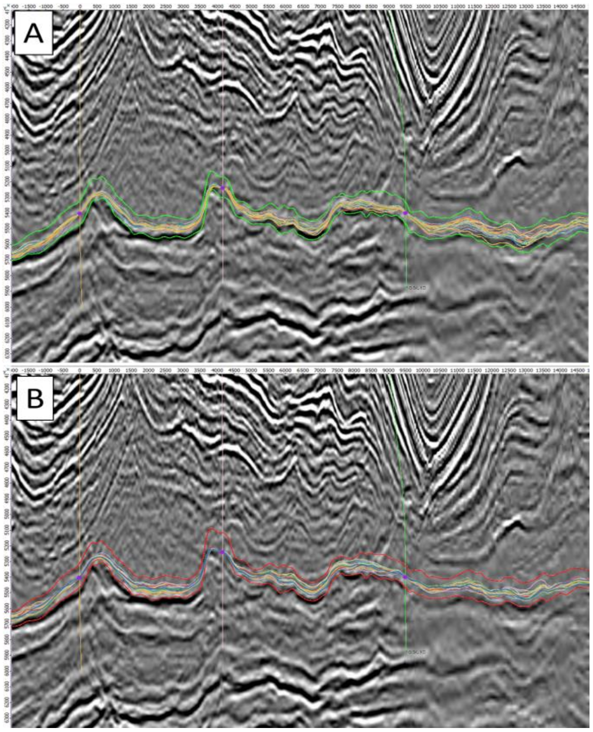


Figure 3: Subset with 20 realizations for each scenario (Scenario 1 – **(A)**; Scenario 2 – **(B)**). The green and red envelopes denote the seismic uncertainty envelopes. The pink points are the well picks.

The GRV from both scenarios were compared, and an increase of about 0.5% for Scenario 2 was observed. Although the percentage is small, the difference can represent considerable changes in the reservoir volumes. This variation, in terms of percentage, is in accordance with the work presented by Meneguim *et al.* (2015), that mentions a variation of up to 3%.

Additional parameters such as Net-to-Gross (NTG), porosity and oil saturation, can also influence oil reserve calculations, and should be included in future uncertainty studies. Investigations may also include the possibility of performing velocity modelling considering not only the average velocities (P50) for the salt facies (Scenario 2), but also the P10 and P90 for the PDF displayed in Figure 1.

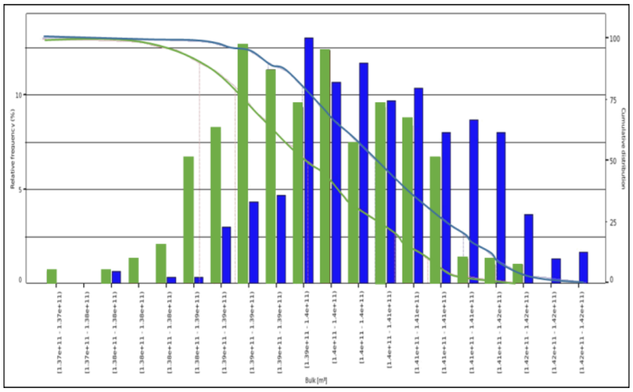


Figure 4: Histogram with all 600 GRV values for both scenarios (blue – Scenario 1; green – Scenario 2). Scenario 2 is slightly more optimistic than Scenario 1.

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References

Amaral, P. J., Maul, A., Falcão, L., González, M. & González, G. 2015. Estudo Estatístico da Velocidade dos Sais na Camada Evaporítica na Bacia de Santos. 14th International Congress of the Brazilian Geophysical Society, Rio de Janeiro, RJ, Brazil. doi: 10.1190/sbgf2015-131.

Barros, P., Amaral, P.J., Girardi, T., Martini, A., Maul, A. and González, M. 2017. Salt-focused inversion in the Santos Basin. 15th International Congress of the Brazilian Geophysical Society, Rio de Janeiro, Brazil. doi: 10.1190/sbgf2017-223.

Fonseca J., Teixeira L., Maul A., Barros P., Boechat J. & González M. 2018. Modelling Geological Layers into new Velocity Models for Seismic Migration Process: A Brazilian Pre-Salt Case. First EAGE/PESGB Workshop on Velocities. London, UK. doi: 10.3997/2214-4609.201800010.

Huang, Y., Lin, D., Bai, B. and Ricardez, C. 2009. Pre-Salt Depth Imaging of Santos Basin, Brazil. 79th SEG Annual Meeting, Houston, Texas, USA. doi: 10.1190/1.3255446.

Ji, S., Huang, T. Fu, K. & Li, Z. 2011. Dirty Salt Velocity Inversion: the Road to a Clearer Subsalt Image, Geophysics, 76(5). doi.org/10.1190/1.3513718.

Jones, I. F. & Davison I. 2014. Seismic Imaging in and around Salt Bodies. Interpretation, Vol. 2, No.4, SL1-SL20. doi: 10.1190/INT-2014-0033.1.

Leahy, G .M and Skorstad, A. 2013. Uncertainty in Subsurface Interpretation: a new Workflow. First Break, 31 (9), 87-93.

Leahy, G. M., Bukhgeym, A. and Yang, W. 2014. Conditioning Geomodels to Seismic Data: a Streamlined Interpretation Workflow. First Break, 32 (3), 111-116.

Maul A., Fonseca J., Teixeira L., Barros P., Boechat J., Nunes J. P., Yamamoto T., González M. & González G. 2018(b). Modelling Intra-Salt Layers when Building Velocity Models for Depth Migration. Examples of the Santos Basins, Brazilian Offshore. 88th Annual Meeting. Anahein, CA, USA. pp. 3764-3767. doi: 10.1190/segam2018-2996209.1.

Maul A., Santos M. C. & Silva, C. G. 2018(a). Few Considerations, Warnings and Benefits for the E&P Industry when Incorporating Stratification inside Salt Section. RBGf – Revista Brasileira de Geofísica, V.36, n.4. doi: 10.22564/rbgf.v36i4.1981.

Meneguim, T., Mendes, S., Maul, A., Falcão, L., González, M. & González, G. 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, Rio de Janeiro, RJ, Brazil. doi: 10.1190/sbgf2015-271.

Pinto, V. R., Abreu, C. E. B. S., Monteiro, R. C., Rosseto, J., Leahy, G. 2017. Seismic Uncertainty Estimation in Reservoir Structural Modelling. First Break, 35 (10), 51-54.

Roque F, Vasconcellos G, Pontes R, Maul A. & González M. 2017. Assessment of Depth Positioning Uncertainties for PSDM Seismic Data. (15th International Congress of the Brazilian Geophysical Society), Rio de Janeiro, RJ, Brazil. doi: 10.1190/sbgf2017-357.

Widess, M. B. 1973. How Thin is a Thin Bed? (Geophysics, 38(6), 1176-1180). doi: 10.1190/1.14440403.