Reviewing the Evaporites Interpretation using Well-Log Information in Santos Basin: Benefits and Applications

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Abstract

The last works developed by the Petrobras geological modeling group of seismic velocities of reservoir geophysics area shows the importance of incorporation of existing stratifications in the evaporitic section, Ariri Formation, is a key point to improve velocity models of Pre-Salt, projects in the Santos Basin. The presented workflow proposed to generate a more realistic seismic velocity model has as key input data the 1D information of the drilled wells. The usage of velocity from sonic information analysis with the aid of the interpreted lithologies along the entire stratigraphic column of the drilled wells is useful. The generation of these lithology logs in the evaporitic and post-evaporitic section is a careful work. It may contain misunderstandings due to the absence of complete well log suites and, in the case of the evaporitic section, due to the return only of the less soluble salts in the wellbore sample. In order to create a more reliable common database, we reviewed the lithology description and interpretation of the evaporitic and post evaporitic sections of about 200 wells in the Santos Basin. Besides drilling parameters, rock data, electrical profiles, field reports the seismic data were very important as guide for correlation among wells with a full suite of logs and wells not properly logged. We present the impact on final reservoir geological and geophysical products such as velocity model building, seismic reprocessing, seismic illumination studies, seismic depth uncertainty scenarios, generation of rock volume studies and geomechanical modeling.

Introduction

In the last few years, we have noticed the great evolution of seismic processing techniques, much because of increased computational capacity. This computational evolution has allowed the use of increasingly detailed velocity models. The detailing of velocity models therefore has been considered a key aspect to obtain the best seismic images. In particular, Jones and Davison (2014) mention difficulties in building seismic images in regions close to salt bodies as a function of lateral velocity contrasts.

Since 2013, Petrobras has a dedicated group from the reservoir team that is investigating geological ways to model seismic velocities searching for the image improvements focusing on the Pre-Salt fields of the Santos and Campos Basins. They were especially concerned with the incorporation of existing stratifications in the evaporitic section, the Retiro Formation in Campos Basin and the Ariri Formation in Santos Basin besides to start to think about the Albian rafts which lies above the evaporitic section in both basins. This formation is an evaporite sequence deposited in a restricted marine transitional post-rift environment of Cretaceous/Neapolitan age (Moreira et al., 2007), and can present variable thicknesses, reaching more than 3,000m, as a function of the halokinesys.

Due to economic reasons, overburden lithological column is not always logged for most of Santos Basin Pre-Salt development wells. Even in logged wells, we may not have the information across the drilling column due to technical problems, such as the phase transition region. The absence of this information compromises the realization of studies such as velocity modeling, seismic-well tie, seismic inversion, facies and uncertainties.

The recent results obtained are showing great value for the Santos Basin Pre-Salt projects (Maul et al., 2015, Jardim et al., 2015, Meneguim et al., 2015, Oliveira et al., 2015, González et al., 2016, Gobatto et al., 2016, Falcão, 2017, Fonseca et al., 2018). All of these studies cited the importance of an in-depth knowledge of the information obtained through well data, such as statistics of values obtained in well logs and lithological interpretation, as presented by Amaral et al., 2015 and Yamamoto et al., 2016). Cornelius and Castagna (2018) cited this same importance for projects in the Gulf of Mexico.

Figure 01 introduces the workflow for modeling stratified salt velocities, bringing the idea that all those steps permeated by the analysis of the seismic velocity logs, derived from the sonic logs, and its complements with the lithological descriptions.

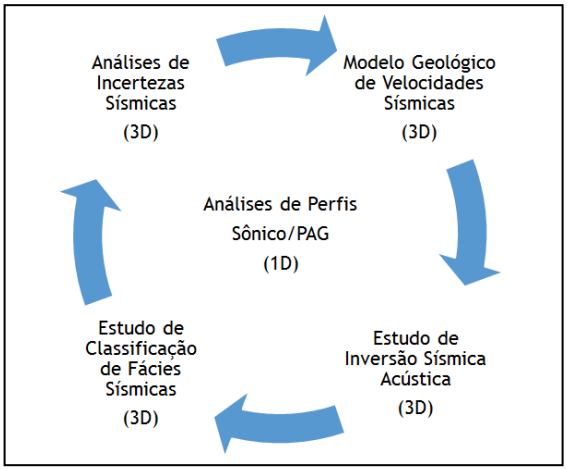


Figure 01: Proposed workflow to produce a more realistic velocity model, Maul et al. (2016).

The possibility of produce and handle more detailed velocity models, including seismic inversion and facies modeling, reinforced the need to have a better lithological interpretation of the evaporitic section, integrating data from rock samples, drilling parameters, geophysical logs and to correlations of the wells between seismic sections. However, as observed by Silva and Rodrigues (2016), the interpretation of the geological column during drilling of wells can generate different results, depending on the used criteria and the acquired data to support this task. Despite needed, interpretation subjectivity in the composition of a geological column may generate errors of various sources.

At the beginning of 2016, Petrobras Pre-Salt reservoirs development department for the Santos Basin projects selected as one of the priority demands the revision of the lithological interpretations in the evaporitic and post-evaporitic sections of all exploratory and development drilled wells. For a huge group of the development wells, in the overburden section, only the well site geological logs were available, which is a draft of the lithological interpretation log performed onboard while or just after drilling, causing an absence of more detailed and reliable information.

This work aims to present the impact and results of this revised interpretation in several wells in the Santos Basin, assessing the benefits and identifying where these lithology logs are being used already, giving magnitude of integration work carried out by several departments inside the company.

Results and Discussions

Silva and Rodrigues (2016), present a technical discussion regarding criteria and data used to generate geological information of the evaporitic section, in a more representative way, according to the reality, for the wells of the Pre-Salt of the Santos Basin. In their work, they demonstrated that the process of interpretation of the lithology descriptions happens in a very dynamic and critical way, integrating data of different natures. This methodology generated new orientations for the composition of the interpreted geological column, with the aim of minimizing the frequent problems and mistakes in the interpretative process. For proper interpretation of well information, we should consider several parameters, such as:

- Phase diameter: large annular diameters and / or washouts will influence the responses obtained in the profiles (requiring at least a good control of the diameter of the well through the caliper logs);

- Drilling fluid: depending on the composition of the drilling fluid the well logs data may be compromised;

- Drilling parameters, such as penetration rate, drill column weight and torque;

The penetration rate represents the natural resistance of rocks to drill, and aids in lithological identification. The weight on column directly influences the penetration rate, *i.e.* it is important to observe both variables before inferring a certain type of lithology. A hard lithology should be hard to drill while a soft lithology should be easier, and weight on column should always be associated with the penetration rate and vice-versa. The torque may be indicative of lithology change when variation of this parameter occurs only.

The association of the geophysical logs with the drilling parameters becomes essential for lithological identification, especially where there is no return of drill samples and/or also scarcity or lack of profiles. It is very common when drilling the initial phases, the absence of samples return and the acquisition of gamma rays and resistivity logs only. This has been the path to follow in order to obtain some information, called 1D, to aid in the 3D modeling of stratifications of the evaporitic section. In this sense, the seismic sections between the wells also has great importance in this interpretation, see Figure 02.

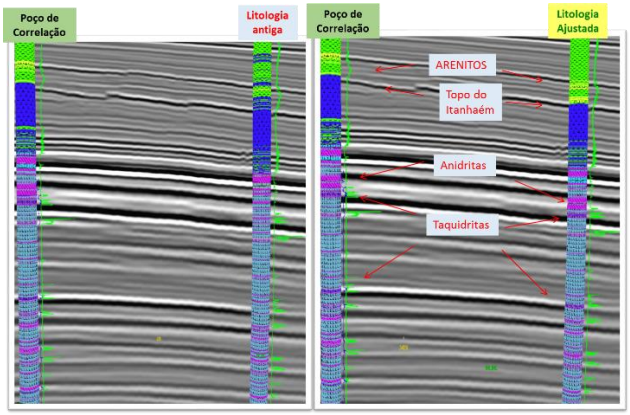


Figure 02: Well correlation and lithology reviewing based on seismic interpretation.

The result of the revision of the lithology log compared to the previously available log in the evaporitic section can be seen in Figure 03 for three Santos basin Pre-Salt wells.

Currently, almost 100% of the wells drilled in the Santos Basin Pre-Salt play have already undergone this process of reviewing the lithology column in the evaporitic section.

Currently we are reviewing the new drilled wells shortly after the completion of the drilling, in order to keep the lithology updated in the database.

The first product obtained directly from the generated lithology profiles is the proportion of the occurrence of the types of salts, now with 100% of its representability, per well, since the absence of profile records was complemented with the lithology descriptions. Figure 04 shows the proportion of occurrence of salts, grouped according to their seismic velocities (low velocity salts - LVS, mainly represented by carnalites and tachyhydrites, "background" represented by halite, and of high velocity salts-HVS, represented by the anhydrite), in the wells studied (Gobatto et al, 2016).

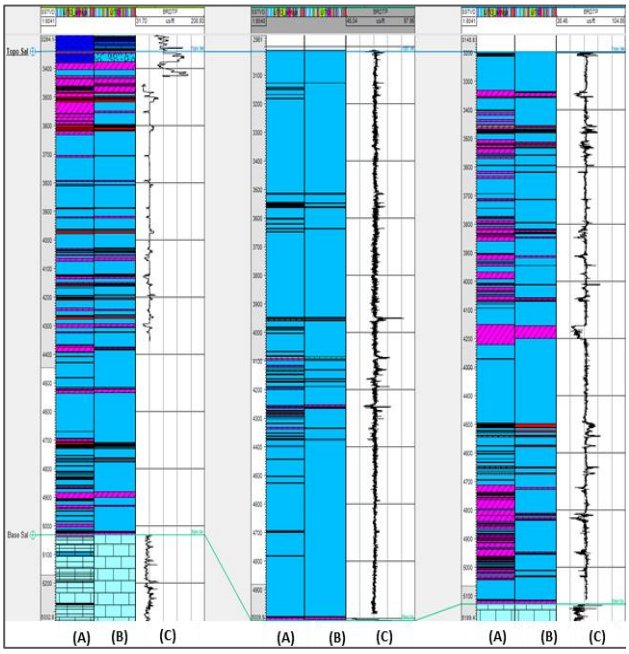
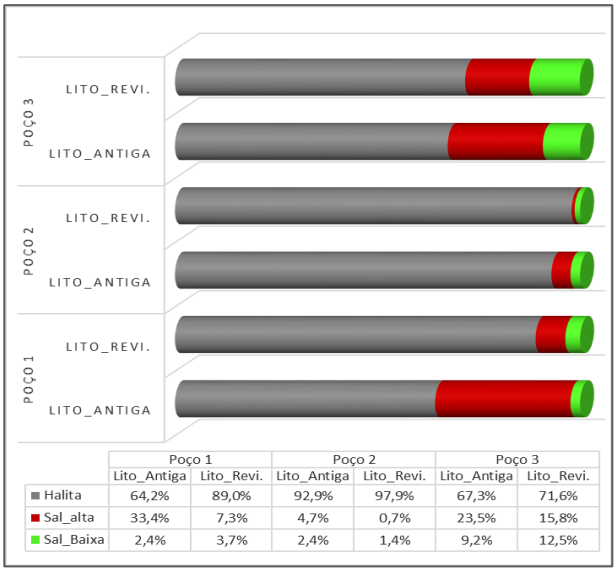


Figure 03: Comparison between two geological column interpretations in few wells. (A) Old interpretation; (B) Current interpretation; and (C) Acquired compressional sonic logs.

Amaral et al. (2015) and Yamamoto et al. (2016) indicate the predominance of halite therein, varying between 80-90% and the remainder distributed between the LVS and HVS. In terms of the occurrence of "types of salts", in their works, carried out in distinct areas, each with about 25 wells. Gobatto et al. (2016) reported these same percentages, in this case considering about 150 wells. Jackson et al. (2015) also supported the mentioned proportions for the same Basin, not mentioning the number of studied wells.



	Poço 1		Poço 2		Poço 3	
	Lito_Antiga	Lito_Revi.	Lito_Antiga	Lito_Revi.	Lito_Antiga	Lito_Revi.
Halita	64,2%	89,0%	92,9%	97,9%	67,3%	71,6%
Sal_alta	33,4%	7,3%	4,7%	0,7%	23,5%	15,8%
Sal_Baixa	2,4%	3,7%	2,4%	1,4%	9,2%	12,5%

Figure 04: Proportion of the occurrence of salts in wells according to their seismic velocities: In gray halite (background), anhydrite red (HVS), and in green other salts (LVS).

Where to Apply the Methodology

The consulted bibliography defend the idea the illumination studies should consider the geological nature in which the rays would be propagated to simulate a more realistic result. In this way, the insertion of the stratigraphic characterization of the evaporitic section carrying out these studies is recommended. Figure 05 illustrates an example carried out in 2014 of refining geological modeling and velocities through well log reviewed. Note that the result presented in C is comparable to A, which is the amplitude map extracted on the reference horizon (top of the reservoir). In the map presented in B, where we used the original velocity model for the seismic migration procedure to perform the illumination study, we lost the correspondence.

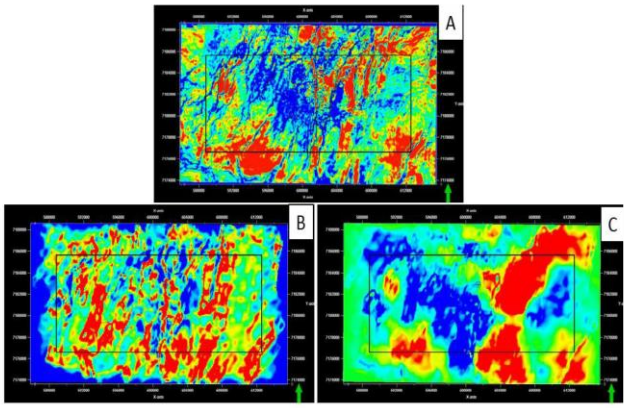


Figure 05: (A) Instantaneous amplitude at the top of the reservoir; (B) Simulated Amplitude at the top of the reservoir, from an illumination study regarding the original migration velocity; (C) Simulated Amplitude at the top of the reservoir, from an illumination study regarding interval velocity with salt stratifications. Images kindly provided by the Geophysicists Rejhane Santos, Roberto Dias & Rodrigo Link (2014).

Seismic reprocessing, especially for those using more precise depth migration algorithms technique, such as the RTM (*Reverse Time-Migration*), requires velocity models as close as possible to the existing geology. In this way, the insertion of the stratifications again becomes important. In even more advanced techniques, such as FWI (*Full WaveForm Inversion*), the initial model must always introduce the most accurate trend possible, in order to obtain a satisfactory final velocity model. The updates of the velocity models by tomographic inversions need to control how far they can operate (boundary conditions). The internal stratifications allies to control the search parameters of these boundary conditions.

Regarding operational safety during field development, especially in the drilling and well planning phases, the characterization of salt strata is an input of high geomechanical value. The generation of salts types and thickness depth scenarios contribute to combat the occurrence of drilling column imprisonment and dynamic drilling fluid loss from wells, often associated with soluble salts.

The estimation of the salt thickness that acts as a seal is also of great importance for the calculation of the maximum injection pressure of each well in the studies of geomechanical simulation of reservoirs, assuring the integrity of a sealing layer allowing the enhancement of the hydrocarbon recovery.

Figure 06 shows a session of the lithological model for the area of a Pre-Salt field of the Santos Basin obtained from seismic attributes and the well lithological reinterpretation, with special emphasis on the salt section: halite (in gray), HVS (purple) and LVS (red).

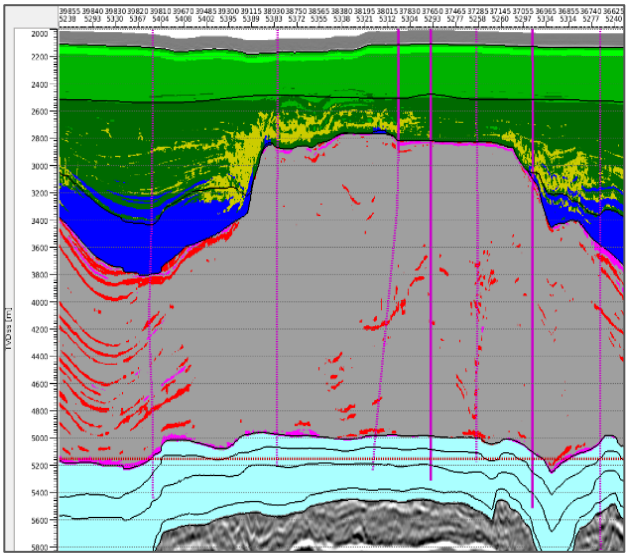


Figure 06: Lithological model in depth, obtained from reinterpretation of well lithologies and seismic attributes.

Conclusions

The ideal lithology interpretation should be performed using sonic and density logs, due to the nature of its investigation and easier identification of salt types. However, this is not an operational reality for the salt and post-salt geological sections in the Santos Basin Pre-Salt fields, during the drilling of the development wells.

In this work, we defend it is possible to have a more realistic interpretation of the evaporitic section, from well data, seismic and rigorous technical foundations of well logs in the identification of salts and their mixtures.

The vicious and misconceptions that resulted in a lower quality of lithological interpretation is supposed to be due to the absence of acoustic profiles. In order to overcome the lack of sonic data we recommended that the lithological interpretation performed onboard also integrate different data sources such seismic data and well correlation to minimize errors and subjective interpretations.

The impact of the incorporation of the lithology profiles interpreted in the salt and post-salt sections of Santos Basin in the various types of geophysical studies is quite clear and promising.

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