Estimating amplitude uncertainties through illumination studies for a pre-salt reservoir

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Abstract

Several discoveries were announced in pre-salt section in Brazilian Basins. There are several discussions regarding the correct way to build the best velocity model for migration purpose (algorithms, constant velocity, isotropy, FWI). These discussions look for how to build the best image only. The amplitude response seems to be a consequence of this built image.

We present a method for uncertainty analysis in seismic illumination studies. Different velocity models were built in order to better understand their impact over the obtained hit-maps (ray-tracing method). The original velocity model is used as reference to compare the initial hit-map against others obtained using different velocity models. Cross-plots are used to assess areas where response values are divergent or where there is greater uncertainty in seismic illumination, and consequently in seismic amplitude response for the reservoir characterization.

With original velocity model as input, we constructed four scenarios regarding the velocity of the evaporitic layer: (1) using the original velocities; (2) constant velocity for the evaporitic complex; (3) geostatistical extrapolation of wells logs; (4) conditioning the evaporitic complex velocity using amplitude as weight factor.

This method can be used to investigate uncertainties and emphasize where amplitude response can be used properly for reservoir characterization.

Introduction

Several discoveries have been announced in Santos and Campos Basins in pre-salt layers (Barra Velha and Macabu Formations). There are many discussions regarding the correct way to build the best velocity model for migration purposes (algorithms, constant velocity, tomography, isotropy x anisotropy, FWI). These discussions usually look for how to build the best image only.

In a reservoir characterization is usually considered that the amplitude response is due only to the impedance contrast of rocks. However, it is known the amplitude response depends on several factors such as geology complexity, acquisition parameters, processing strategy, etc. (Hari Lal *et al*, 2010). The presence of both homogeneous and layered evaporites and faults that could overhang the carbonates and mini-basins in the post-salt section makes the velocity model building workflow more challenging when compared to other areas such as in the Gulf of Mexico (Zhang *et al*, 2008 and Huang *et al*, 2009) (Figure 1).

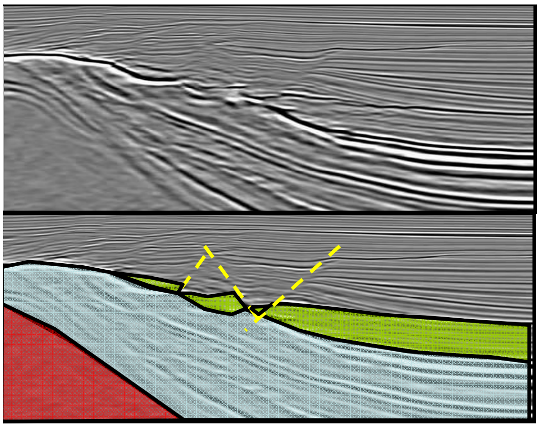


Figure 1: Complex geological scenario: seismic section and schematic interpretation. Green represents the post-salt carbonates, blue the stratified evaporites and red the domic salt.

Due to the difficulty to ensure which are the main factors that cause these amplitude uncertainties, it is mandatory to evaluate the amplitude response before using it. Furthermore is reasonable to add the geology complexity in the velocity model construction, frequency content and other considerations.

Jardim *et al*, 2014 and Maul *et al*, 2015 presented a method for uncertainty analysis in seismic illumination studies. Different velocity models were built in order to better understand their impact over the obtained hit-maps (generated by ray-tracing method). The original processing velocity model is used as reference to compare the initial hit-map against others obtained using different velocity models. Cross-plots are used to assess and to identify areas where response values are divergent, or in other words, where there is greater uncertainty in seismic illumination, and consequently for the seismic amplitude response.

This method can be used to investigate and compute uncertainties and emphasize where the amplitude response can be used properly for reservoir characterization.

One seismic amplitude map of reservoir top was extracted from the seismic cube migrated using the original velocity (Figure 2).

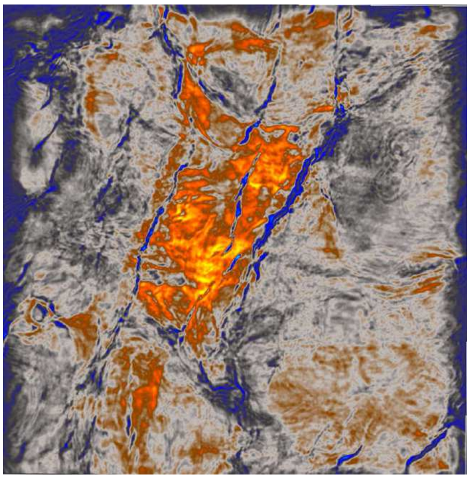


Figure 2: Seismic amplitude map of the reservoir top. Demonstrates a distinctive NE-SW related to carbonate build-ups and faults. Orange amplitude delimits the reservoir.

Methodology for input generation

Four velocity models were constructed with specific consideration for the evaporites layer to perform the illumination study in an isotropic approach:

1) The interval velocity obtained from seismic tomography in the pre-stack depth migration processing (Figure 3A).

2) A model with constant velocity for the evaporitic complex. Velocity was estimated from a statistical analysis of the instantaneous velocity using 4 wells (Figure 3B).

3) A velocity model derived from a seismic pattern recognition study and a geostatistical approach for extrapolation of the velocity logs. A volumetric seismic facies analysis over the calculated seismic energy defined two domains: stratified (high energy) and homogeneous (low energy). A grid deformed by seismic interpretation was built for the well-log velocity extrapolation and treatment in the stratified domain. In the homogeneous domain a constant velocity was considered (4500 m/s) (Figure 3C).

4) A velocity model generated with amplitude as a weight factor into the evaporitic complex in order to achieve better representation of the heterogeneities. Based on velocity logs and lithological interpretation, high positive amplitudes were assumed as Anhydrite (interval velocity = 5900m/s), low negative values as Carnallite (interval velocity = 3900m/s) and intermediate values as halite (interval velocity = 4500m/s) (Figure 3D).

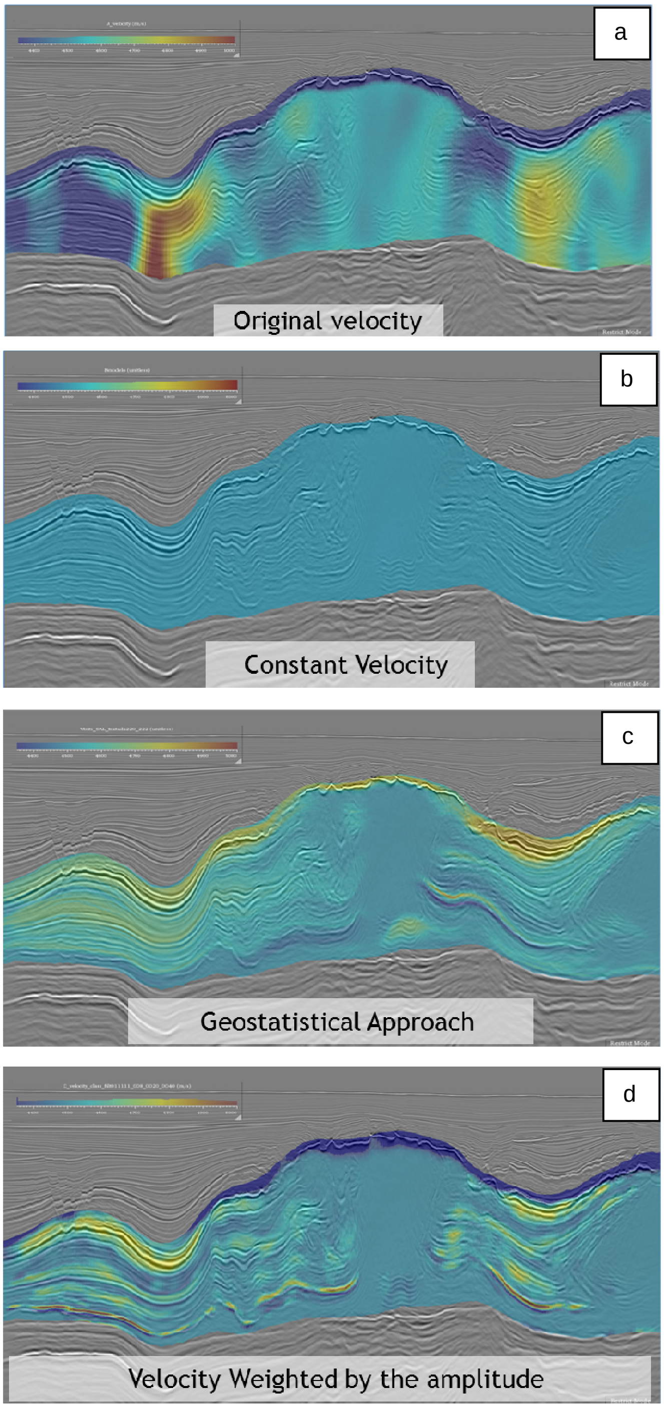


Figure 3: Original salt velocity model **(a)**; Constant salt velocity **(b)**; Geostatiscal Approach using a seismic pattern recognition study and the logs **(c)**; Weighting the salt velocity using the amplitude signal **(d)**.

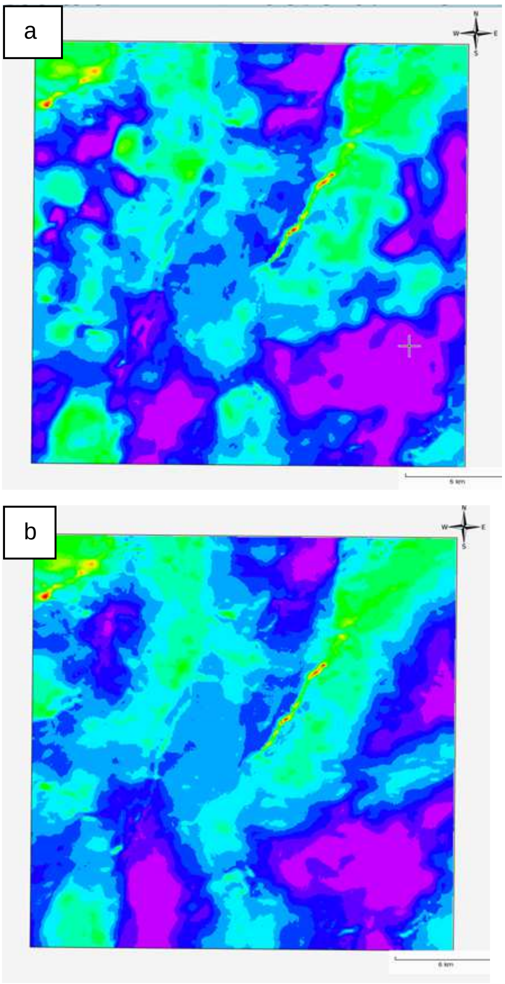
Methodology for hit-maps construction

Subsurface illumination analysis provides a technology bridge for understanding the dependencies of the velocity model, migration parameterization and seismic acquisition on the seismic image (Laurin *et al*, 2004a and Laurin *et al*, 2004b).

A ray tracing in batch approach that quantifies the relation between the surface acquisition geometry and the subsurface angles in target areas was used in order to obtain the hit count maps for each velocity scenario. Input for this tool includes the velocity model and the structural map (isotropic assumption).

Several considerations and parameterizations (aperture, maximum input offset, opening angles and ray filters) were tested to find a unique template for the ray tracing processes for each velocity model.

For this analysis were generated four hit-count maps to be considered (Figure 4).



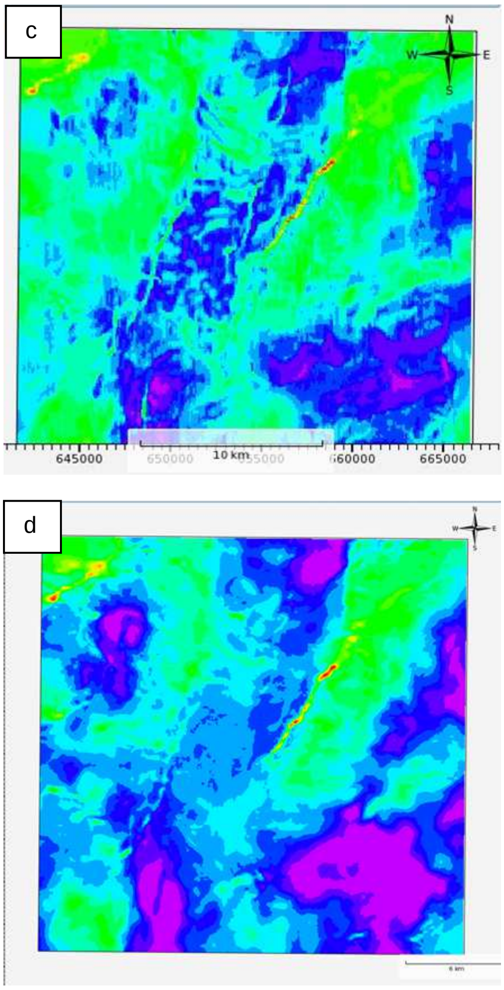


Figure 4: Hit-maps from the ray tracing, considering: the original velocity model as input **(a)**; a constant velocity for the evaporites layer **(b)**; a velocity model built through a combination of volumetric facies classification and a geological/geostatistical approach **(c)** and the velocity model weighted by the amplitude response into the evaporites layer **(d)**.

Cold colors (blue tons) represent zones with more successful rays. The high values southeast region matches with the salt layer thinning.

Methodology for results analysis

The first evaluation was to compare all the hit-maps, the extracted seismic amplitude and the evaporites layer thickness map together. The goal was try to identify how the interval velocity and the evaporites layer thickness influence over the instantaneous amplitude of the reservoir top.

Then was used the proposed cross-plotting approach to appraise the several hit-maps obtained and the identification of regions where the response values are divergent.

These divergent regions were plotted over the amplitude map (reference case) in order to create a highlighting map that offers the confidence degree for the amplitude response for reservoir seismic characterization studies (Figure 5).

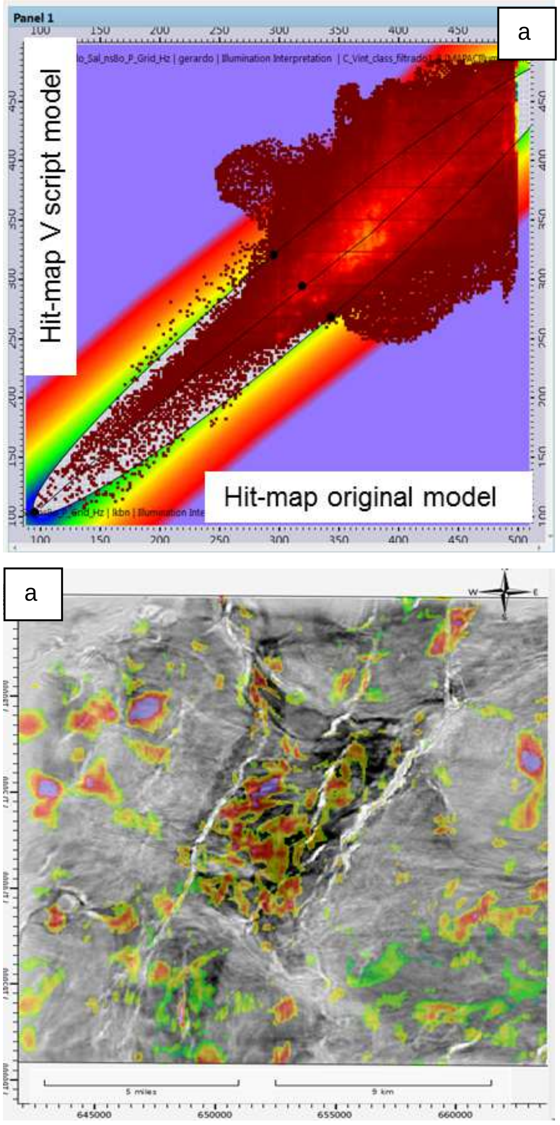


Figure 5: Hit-maps cross-plot. In this particular case, most of the points are well correlated. Observed dispersion could be interpreted as areas of lower amplitude confidence **(a)**. Hit-maps crossploting analysis. High-lighting map over amplitude map suggesting lower confidence areas **(b)**.

Conclusions

As expected the way to build the velocity model influences the ray tracing study. Build an accurate interval velocity model is a key point to have a representative image response. The use of the amplitude response versus hit-maps indicated the portions where the amplitude response could be used with confidence to populate reservoir properties as a trend guide.

The uncertainties estimation of this kind of study is an important tool as it takes in account several approaches and consideration during quantitative seismic interpretation processes.

The models created by velocity logs extrapolation and based on amplitude better represent the subsurface heterogeneities, if compared to the original model. A combination of these two methods should be evaluated.

The used ray–tracing method is more indicated for low complexity in terms of geology once it needs to take smoothed velocity model which is not the case for the studied area. There are other approaches for these scenarios such as wave front construction (WFC), finite differences, and complete wave equation.

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