# Effects of Post Stack Seismic Data Conditioning on Impedance Inversion for Reservoir, Santos Basin, Brazilian Pre-Salt

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## Abstract

There were several oil and gas discoveries over the last decade in the Pre-Salt section of Santos Basin, Brazil.

Seismic data plays is a key hole in the oil and gas field development project through qualitative/quantitative seismic interpretation, facies modelling, geomechanical studies and uncertainties analysis (Meneguim *et al.*, 2015 a & b and Meneguim *et al.*, 2016).

The Brazilian offshore Pre-Salt reservoirs located in Santos Basin, are plays underlying structurally complex area roughly due to: presence of complex salt structures (walls, diapirs, canopies and salt welds) with complex salt stratigraphy (too many heterogeneities: anhydrite, gypsite tachydrite, carnallite and sylvite) (Yamamoto *et al.*, 2016) and a thick siliciclastic albian wedge above them, imposing several challenges regarding the seismic amplitude response (Maul, *et al.*, 2015).

Therefore, it makes necessary a customized seismic data conditioning process that improves signal-to-noise ratio (SNR) reducing noise associated to salt multiples and migration artifacts but carefully performed to keep on the geological features on the data.

The main objective of this article is to compare reservoir acoustic inversion when using raw seismic data and conditioned seismic data as input.

Acoustic impedance will be compared in two processes:
→The first one was done with the raw data vs. the noise-reduced one as inputs for reservoir acoustic inversion - study case A.
→The second one was done with the noise-reduced data vs. the spectral enhancement one (which has the noise-reduced data as input to generate it) as inputs for reservoir acoustic inversion – study case B.

This study provides higher quality reservoir acoustic impedance, seismic amplitude and shrinks uncertainties in qualitative/quantitative seismic derived atributes.

## Introduction

The Brazilian Pre-Salt carbonatic reservoirs were studied in this work. These are offshore areas (~250Km east away Rio de Janeiro city) composed by microbialites of Aptian age (Barra Velha Formation) in ultra-deep water (~2,4km water column).

Seismic amplitude (Figure 1) in this magnitude of depth (reservoirs with more than 5000 m deep) is affected by many ways:

1) High occurrence and strong signature of multiples/migration (smiles and frowns) artifacts related to the huge variation of the salt thickness.

2) Imaging problems regarding illumination issues – not homogenous salt topology does shadow zones.

3) Frequency range – Loss of low frequency in seismic acquisition (source and receiver ghosts) and loss of the high frequencies due to absorption effect (siliciclastic Albian wedge add to salt layer)

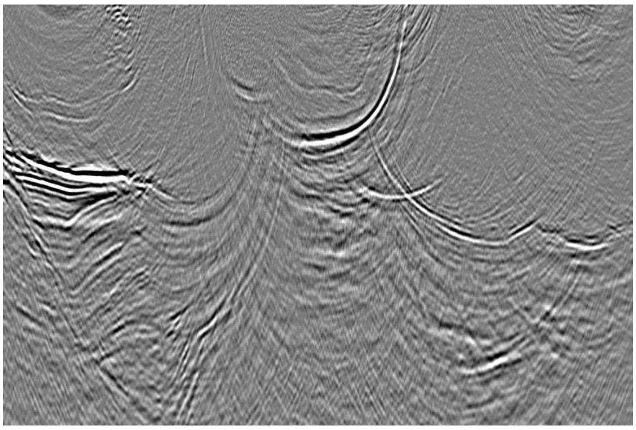

**FIG 1**: *Pre-Salt migrated seismic amplitude in a full-stack section illustrates brutality of several multiples / migration smiles.*

In that context, data has a lot of noise associated to the salt multiples and migration smiles, it'll be proposed a methodology to reduce this sort of noise which has a different approach in comparison to the most common ones methodologies.

Seismic data must regard very intense attenuation when it comes about the frequency content. So once generated the noise-reduced data, it is used as input in a process of spectral balancing in the target level to improve the vertical resolution.

The main objective of this article is to use the conditioned data as input for the acoustic inversion to get better results when it is compared to the same process made with the raw data. It will be also showed the impact in quantitative interpretation when data has been conditioned.

### Method

Firstly will be described seismic data conditioning methodology for two study cases (“A” and “B”), secondly we refer to reservoir acoustic inversion.

### Seismic Data Conditioning

The workflow (Figure 2) used to reduce the seismic noise:

1→Calculate a grid oriented filter (large filter in XY directions and small in Z to reduce the continuity of the vertical noise associated to the salt multiples/migration smiles.

2→Intending to steer the structurally oriented filter it was computed the dip and azimuth (reference volume) using the product of the first step as input

3→Finally, it was applied to the original volume a structurally oriented mean filter (Figure 3), guided by the reference volume.

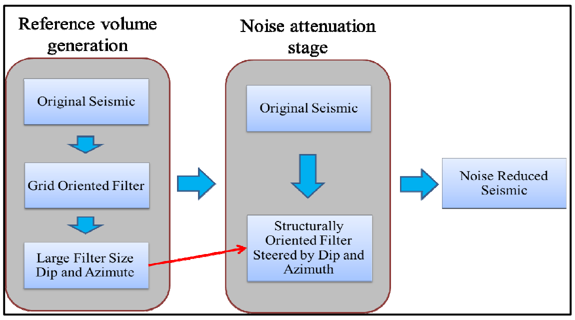

**FIG 2**: *Seismic Noise Attenuation Workflow.*

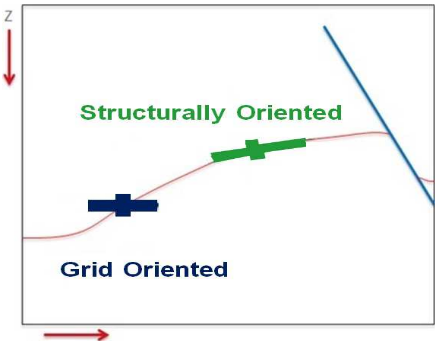

**FIG 3**: *Grid oriented vs. Structurally oriented filter.*

The structurally oriented filter is a simple mean 3D window which runs across the data, voxel by voxel, calculating the local mean according to the orientation given by the reference dip and azimuth volume. The filter size window was chosen according to the level of noise on the data.

Once generated the noise-reduced volume as described above, we watch out frequency content issues.

Loss of seismic frequency content into the reservoir’s overburden strongly affects reservoir characterization. In order to minimize that is effects it was performed a robust spectral enhancement at the target level. Any such a process consists in a frequency decomposition, multiplying these generated frequency sub-bands by a weight according to its energy and then sum them to the noise reduced spectral data (Figure 4)

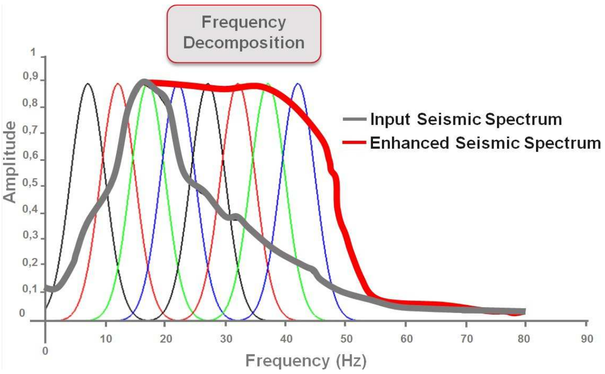

**FIG 4**: *Illustrating sub-bands decomposition adds to input seismic spectrum.*

The sub-band decomposition is controlled interactively taking care to does not rise the high/low-frequency noise

Structurally oriented filter was applied in both Pre-Salt dataset case studies: A and B. Dataset B has suffered a spectral enhancement after structurally oriented filtering.

### *Acoustic Inversion*

In geosciences, through reflection seismic data, seismic inversion process estimates quantitative rock-petrophysical properties such as: porosity, lithology and fluid saturation of a reservoir. (Francis A., 2005)

This important process, in a simply way (referring to CSSI - Constrained Sparse-spike inversion), is based on straightforward convolution of a reflectivity model and an estimated wavelet to produce synthetic traces which are compared to the seismic input, then reflectivity model is updated to ensure carefully: matching between the synthetic and seismic data, the impedance lateral/vertical suavity and sparsity (Figure5) (Tonellot, *et al.* 2001).

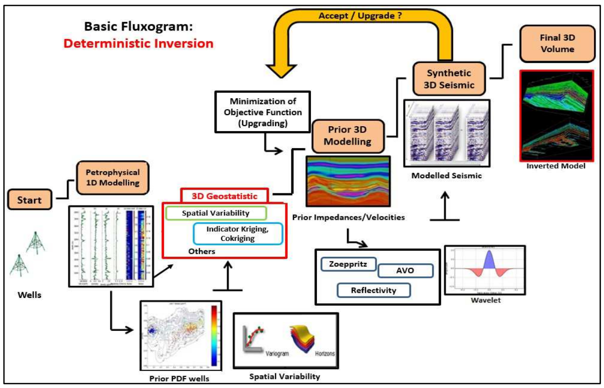

**FIG 5**: *Schematic Seismic Inversion Workflow.*

Changes in acoustic inversion will be exhibited for both Pre-Salt study cases (A and B) allowing us understand structurally oriented filtering and spectral enhancement effects isoladly.

## Results

### Seismic Data

The raw seismic data (Figure 6) is compared to the noise reduced (Figure 7) one - structurally oriented filtered- for study case A.

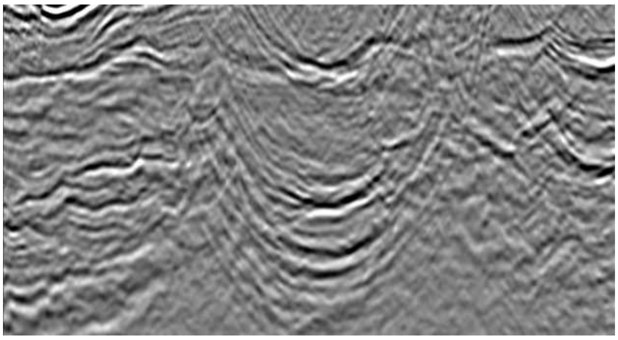

**FIG 6**: *Depth migrated section - Raw Data, study case "A".*

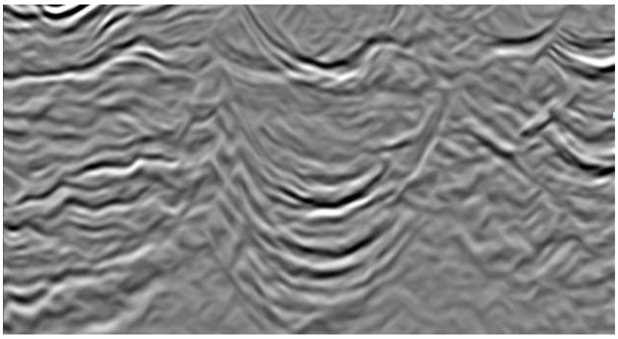

**FIG 7**: *Structurally oriented filtered section – Noise Cancelled Data, study case "A"*

A difference section is also included (Figure 8) for QC

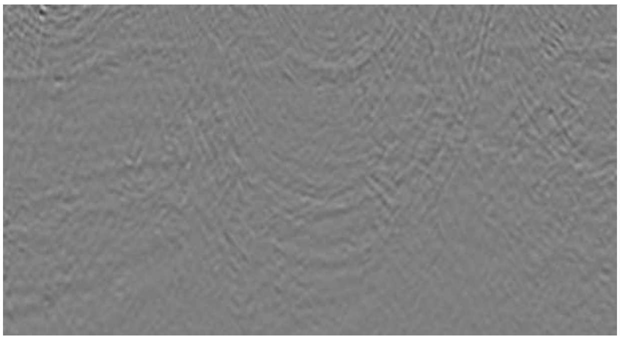

**FIG 8**: *Difference section for study case "A" data*

For the study area "A" it was analyzed structurally oriented filtering effects. We note a significant reducing of the high- dip noise artifacts and our main gain was lateral continuity improvement of the events.

Now for study case B, the structurally oriented filtered data (Figure 9) is compared to the spectral enhanced (Figure 10) one (just remembering, structurally oriented filtered data was the input to spectral enhancement)

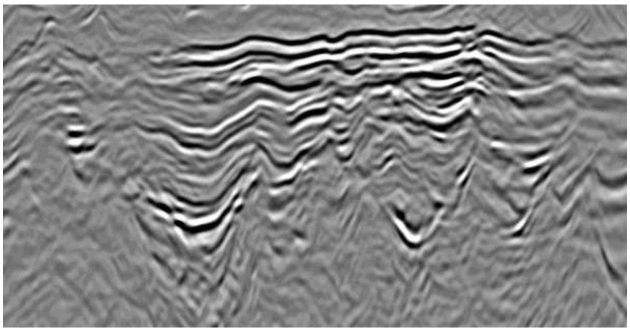

**FIG 9**: *Structurally oriented filtered section – Noise Cancelled Data, Study case "B"*

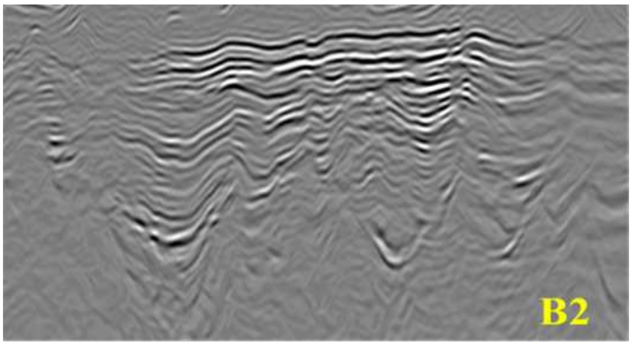

**FIG 10**: *Spectral Enhanced Data, Study case "B"*

For the study area "B" it was analyzed spectral enhancement effects. Our more valuable gain was vertical resolution improvement and reducing tuning effects.

Next, it was compared amplitude spectrum (Figures 11 & 12) as well as wavelets both "A" and "B" study cases.

**For the Case Study A:**

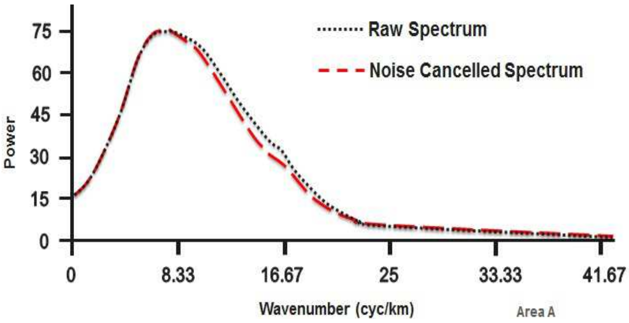

**FIG 11**: *Comparing amplitude spectrum- Raw Data vs. Noise Cancelled Data*

Attenuating noise content gives more confidence (Figures 6 & 7) in attributes interpretation keeping the amplitude spectrum shape very quite similar, as we hope.

**For the Case Study "B"**:

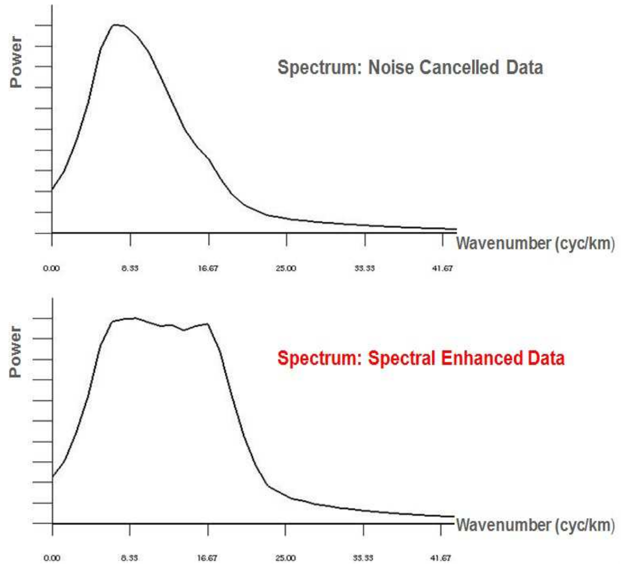

**FIG 12**: *Comparing amplitude spectrum – Noise Cancelled Data vs. Spectral Enhanced Data. (Noise Cancelled Data was the input to spectral enhancement)*

In Pre-Salt context, spectral enhancement increases the seismic resolution and the spectrum bandwidth rebalancing the high frequencies energy. Our goal was compensate the energy attenuated by the earth in the high frequencies.

Now, it was studied wavelets behavior (Figures 13 & 14)

**For the Case Study A:**

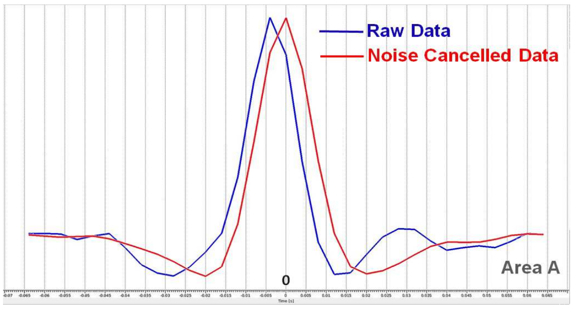

**FIG 13**: *Comparing Wavelets - Raw Data vs. Noise Cancelled Data (x-axis: Time(s))*

The structurally oriented noise filtering has results in a better-behaved wavelet: symmetric and 0-phase centered. It is pointed out the intensity of noise it suffices to introduce a remarkable time- shift and lobes distortion at the raw data wavelet. Both wavelets has very quite similar band-width (frequency content) in agreement to Figure 11.

**For the Case Study "B"**:

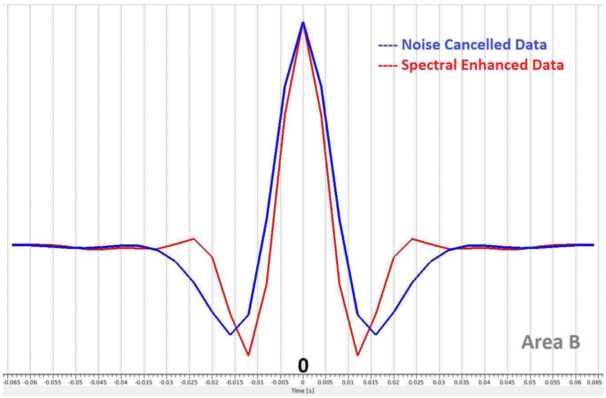

**FIG 14**: *Comparing Wavelets – Noise Cancelled Data vs. Spectral Enhanced Data (x-axis: Time(s))*

Both wavelets are almost 0-phase which is reasonable since noise has already been attenuated in noise cancellation step (structurally oriented noise attenuation). It is pointed out the band-width increase, meaning higher frequency content to Spectral Enhanced Data in agreement to Figure 12.

Finally, it will be considered the effects on reservoir acoustic inversion for study cases "A" and "B".

For study case "A", Figures 15 & 16 shows, respectively, total band acoustic impedance using raw data and acoustic impedance using noise cancelled data (structurally oriented noise attenuation).

Colours nearer yellow have low impedance and nearer blue have high impedance.

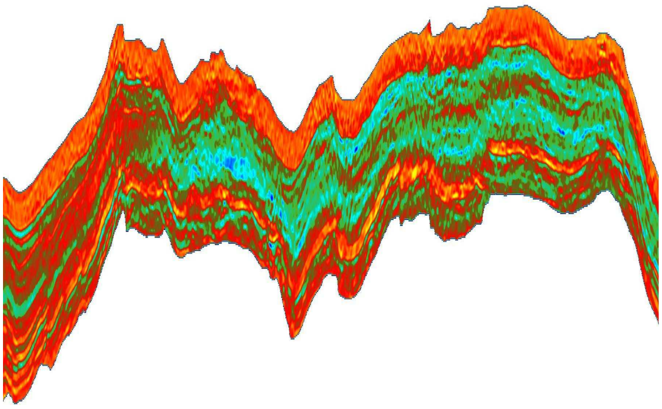

**FIG 15**: *Reservoir Acoustic Impedance using raw seismic data, area "A"*

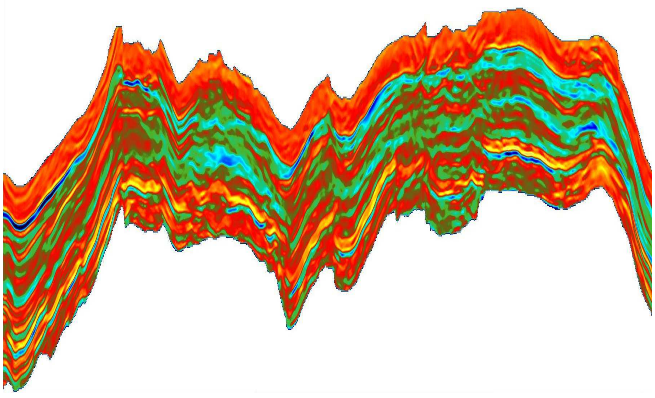

**FIG 16**: *Reservoir Acoustic Impedance using noise cancelled data, area "A"*

Observing Figures 15 & 16, our main gain was lateral / vertical continuity and much less high-dip salt noise marks.

Since we have observed significant changes in FIG 15 & 16, we should hope better results in qualitative /quantitative interpretation: strata-slice maps, mean maps and even geobodies extraction. At really, that is why we believe data conditioning it is a worthwhile area to study.

Next for study case "B", Figures 17 & 18 shows, respectively, total band acoustic impedance using noise cancelled data and spectral enhanced data (just remembering, noise cancelled data was the input to spectral enhancement).

An important detail: in despite to perform acoustic inversion changing seismic data, we state: initial model and inversion parameterization have remained the same for each study case A and B.

In a such way, better results in acoustic impedance comparing Figures 15 & 16 (Case Study "A") and Figures 17 & 18 (Case Study "B") are attributed only to seismic data improvements.

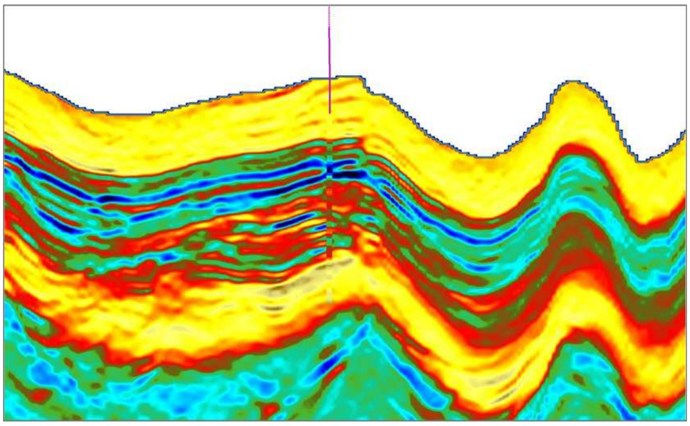

**FIG 17**: *Reservoir Acoustic Impedance using Noise Cancelled Data, area "B"*

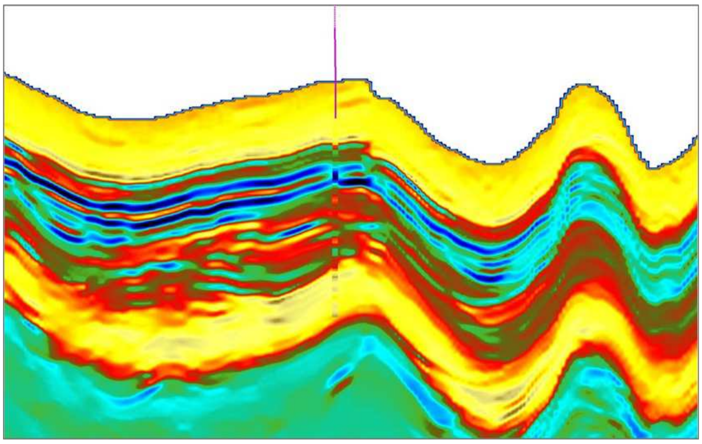

**FIG 18**: *Reservoir Acoustic Impedance using Spectral Enhanced Data, area "B"*

Observing Figures 17 & 18, our more valuable gain was vertical resolution and reducing tuning effects.

In fact, to the well presented in Figures 17 & 18 (purple vertical track) we get better results in inverted acoustic impedance to spectral enhanced data rather than only noise cancelled data.

## Conclusions

Seismic data conditioning has shown to be an essential tool for reservoir characterization.

Seismic amplitude (Figures 6 & 7 – Case Study "A"), (Figures 9 & 10 – Case Study "B") and reservoir acoustic impedance (Figures 15 & 16 – Case Study "A"), (Figures 17 & 18 – Case Study "B") has shown quite clearly higher quality: improvement of lateral/vertical continuity and much less Salt noise than the raw seismic data (for Case Study "A") and area "B" has also improved the vertical resolution since it suffered a spectral balancing workflow.

Estimated wavelet based on conditioned seismic dataset (structurally oriented noise attenuation) of field “A” is characterized by a more symmetrical, centered at 0-time peak and more well-behaved side lobes than estimated wavelet based on raw seismic dataset (Figure 13)

Estimated wavelet based on spectral enhanced data (it was runned after structurally oriented noise attenuation) of field “B” is characterized by recovered frequency content rather than estimated wavelet based on noise cancelled data (structurally oriented filtering).

Amplitude spectra extracted from raw data and noise cancelled data of field “A” have showed a very quite similar shape (Figure 11), meanwhile for field B amplitude spectrum extracted from spectrally enhanced data has showed higher recovered frequency content rather than noise cancelled data (Figure 12)

The benefits obtained for both Case Studies (A and B) suggests a structurally oriented filtering followed by spectral enhancement as an efficient and quick way to face migrated full-stack reservoir seismic data.

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