Prestack AVA-FWI Elastic Inversion of an Onshore Brazilian Data: a Case Study

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Abstract

We present a case study involving the application of a prestack full-waveform elastic inversion on a Brazilian onshore data. Prestack full-waveform elastic inversion considers all wave propagation effects in layered media like converted waves, internal multiples and transmission effects. However, applying this robust technique in land data is challenging due to high noise and frequency band limitations. To overcome these obstacles, the data were submitted to a detailed preconditioning workflow that comprises random and coherent noise removal steps, residual moveout and signal attenuation correction. Applying these routines guided by meticulous quality control of the amplitudes provides stable and quantitative coherent results from FWI elastic inversion despite the limitations of the input data.

Introduction

Reliable recovery of information about the three elastic parameters (P and S-wave velocities and density) from seismic data using AVO formulations requires the use of joint PP-PS inversion (Niebuda et al., 2008). Conventional PP AVO suffers from theoretical limitations and noise sensitivity, restricting stable inversions to at most two parameters (Ursenbach & Stewart, 2008).

Because of that, data preconditioning is a critical step in inversion workflows. Besides improving the signal-to-noise ratio, it is essential to reinforce the amplitude preservation requirement, granting that the inversion is not compromised. Therefore, quality control is carried out at each stage of signal conditioning.

A theoretically more robust seismic inversion formulation is the amplitude versus angle – full waveform inversion (AVA-FWI), since it considers all wave propagation effects in layered media, such as converted waves, internal multiples and transmission losses, and is not limited to low angles of incidence (Oliveira and Franco, 2015).

We conducted an AVA-FWI inversion case study on prestack seismic data from a Brazilian onshore oilfield showing severe amplitude distortions due to random and coherent noise. Before the inversion, we applied a preconditioning workflow to improve the signal-to-noise ratio, mainly for recovering amplitudes fidelity, which is fundamental to obtaining elastic parameters from a prestack inversion.

Preconditioning

In the prestack data preconditioning, the first step was the application of top mute to remove stretching noises. Next, the MultiFilt tool (Braga, 2011) was applied to remove random and coherent noise. Then, we applied the WRMO tool (Braga, 2011) to normal moveout correction of the events in the Wavelet Transform domain. Finally, the HighSeis tool (Braga & Moraes, 2013) corrects the attenuation effect. The data preconditioning workflow can be seen in Figure 1.

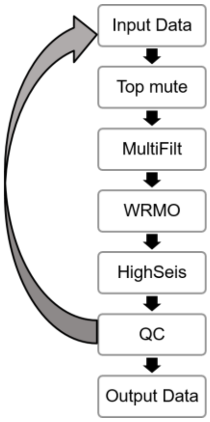


***Figure 1** – Prestack seismic data preconditioning workflow.*

The synthetic data gathers computed from the well logs P-wave velocity (VP), S-wave velocity (VS) and Density using the Zoeppritz equation are used for the quality control (QC) stage. The wavelet is statistically extracted from the seismic data in the region of interest. The idea is to compare modeled and observed AVO curves in each seismic data preconditioning workflow step. Figures 2 show a series of five gathers beginning with the original data (a) followed by three intermediate stages of the preconditioned workflow (b)-(d), and by the synthetic gather (e). In the lower part of the figure, an AVO anomaly plot shows curves corresponding to the red and blue lines indicating the amplitude picks from the gathers. Figure 3 compares synthetic, original, and final preconditioned data. Note the difference between original and preconditioned curves when contrasted with the synthetic data.

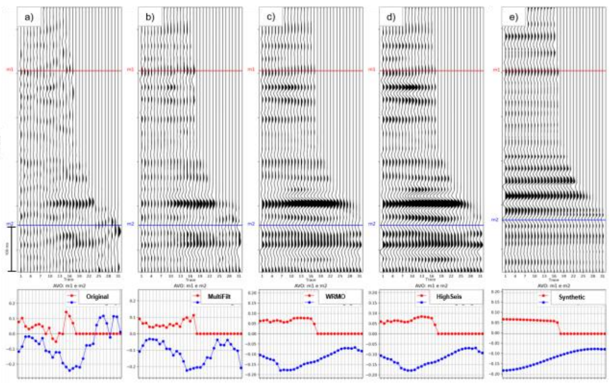


***Figure 2** – Stages of prestack seismic data preconditioning compared to synthetic data and their respective AVO curves to quality control. Offset gather after (a) top mute, (b) random and coherent noise removal, (c) residual moveout correction, (d) inverse Q filter and (e) the synthetic seismic data.*

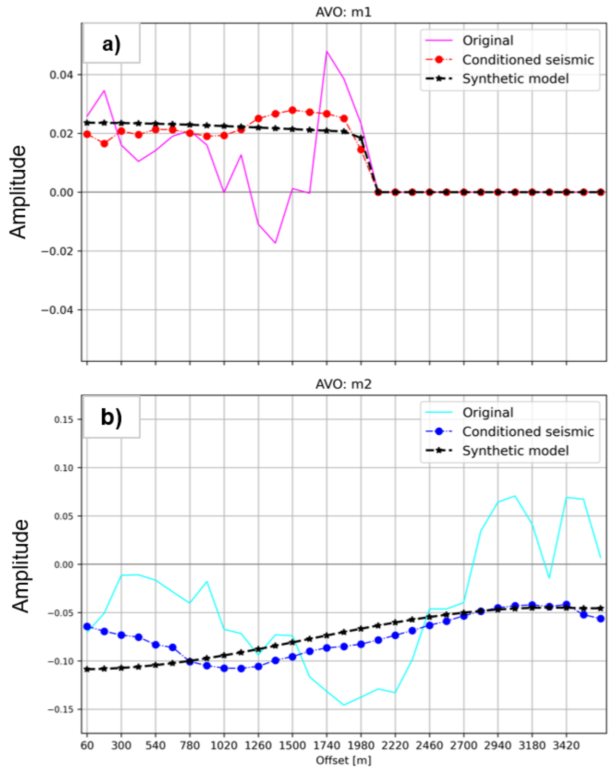


***Figure 3** – Comparison between AVO curves for the original, preconditioned and synthetic seismic gather. AVO curves for the (a) first and (b) second markers.*

Partial stacks were generated using the preconditioned prestack volume data at angles ranging from 3.5 to 38.5 at step of 7 degrees, and the same process was done to the synthetic data. In Figure 4, it is possible to see the comparison between the angle gathers and the AVO Curves for both synthetic and preconditioned seismic data.

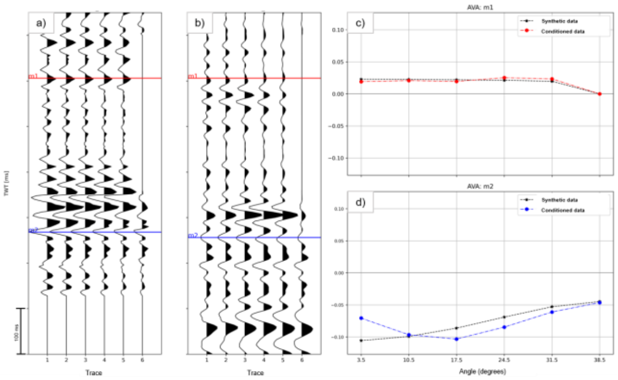


Figure 4 – Figure 4 – Comparison between seismic angle gather (a) synthetic and (b) preconditioned and their respective AVO curves for both gathers at (c) first and (d) second reference markers.

After prestack seismic data preconditioning, the gathers were stacked. In Figure 5 presents the original (b) and preconditioned (a) seismic sections. Notice the significant improvement in the signal-to-noise ratio of seismic data after preconditioning and the spectrum equalization in preconditioned seismic data compared to the original one.

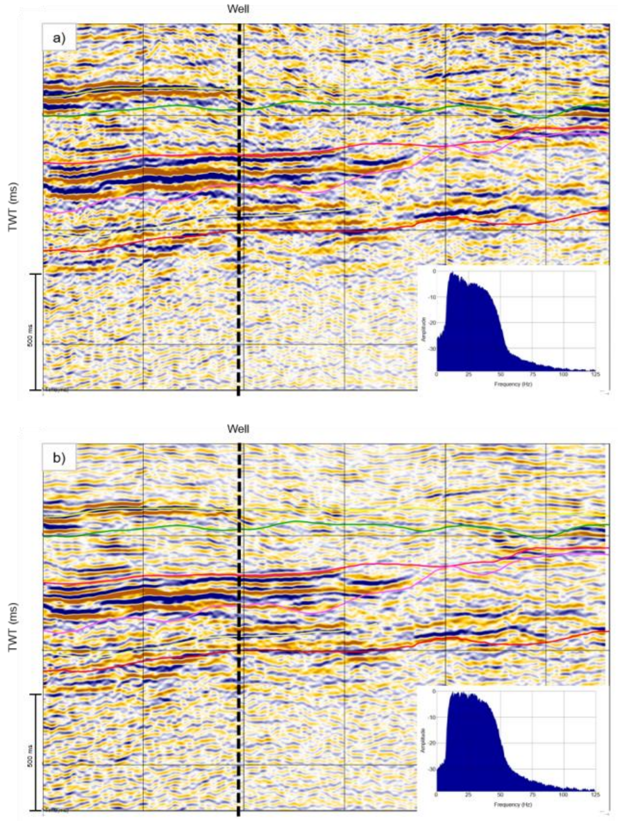


***Figure 5 –** Stacked seismic data with their respective amplitude spectrum (a) after and (b) before the signal preconditioning.*

AVA-FWI Inversion

This method uses optimized computational routines based on the reflectivity method to efficiently calculate synthetic angle gather and differential angle gather (Oliveira et al., 2018). This method works on common angles gathers seismograms derived from the image gathers produced by migration. As the reflectivity method, AVA-FWI is designed for a locally 1-D earth model, as the conventional linearized AVA inversion. Because the method does not involve the simplifications assumed by the conventional elastic AVA/AVA inversion, it produces superior results, as Oliveira et al. (2019) demonstrated. However, the AVA-FWI workflow is similar to conventional AVO/AVA inversion.

In Figure 6, it is possible to observe the comparison between the preconditioned seismic angle gather and the synthetic angle gather. In the sequence, Figure 7 compares the absolute elastic parameters resulted from AVA-FWI inversion with those from the well logging.

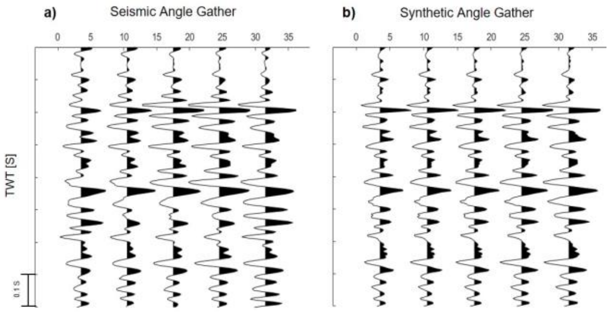


Figure 6 *– Comparison between (a) preconditioned seismic angle gather and (b) synthetic angle gather*

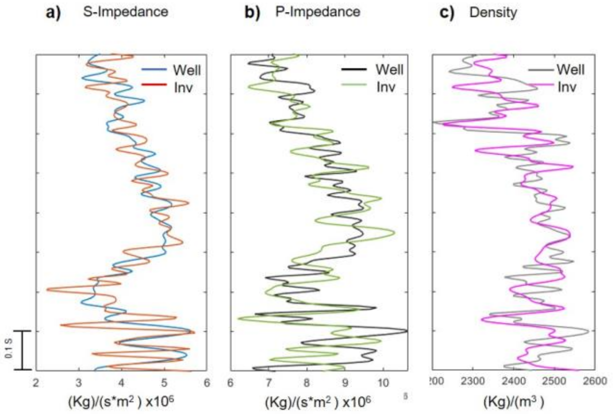


Figure 7 *– Absolute elastic parameters - (a) S-Impedance, (b) P-Impedance and (c) Density - resulted from AVA-FWI inversion in comparison with those from well logging*

Initial models (Figure 8) were created to recover the low frequency content of the seismic data. These models were obtained from the construction of horizons and using the well logs of VP, VS and Density after applying a low pass filter of 8Hz.

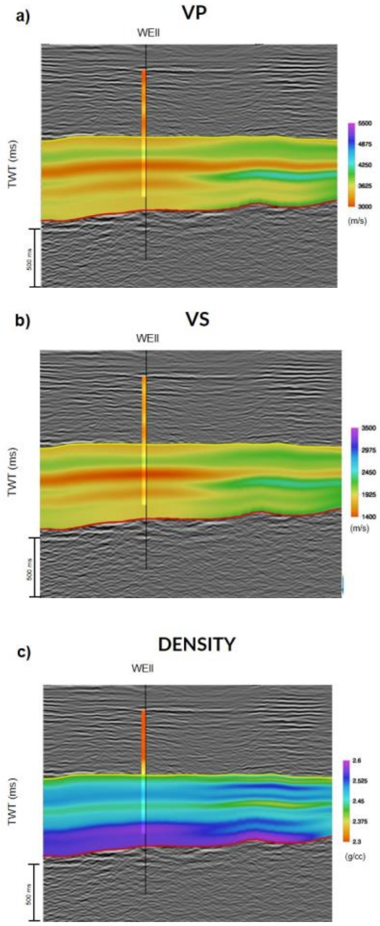
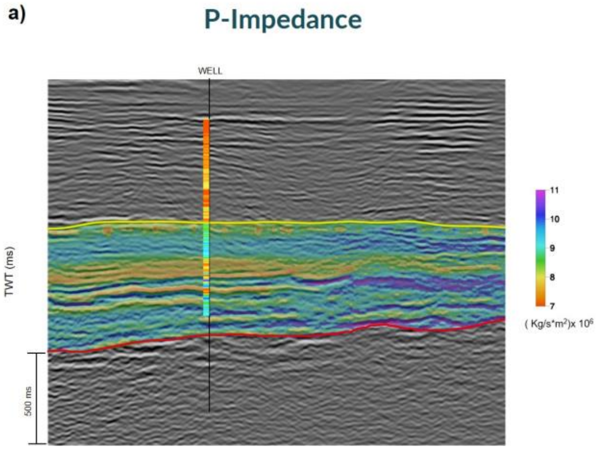


Figure 8 *– Initial models of VP (a), VS (b) and Density (c) created to recover the low frequency content of the seismic data.*

Absolute P, S Impedance and Density

Finally, after building the initial low-frequency models and performing the AVA-FWI inversion, we get the absolute elastic attributes P-impedance, S-impedance and Density, as presented in Figure 9.



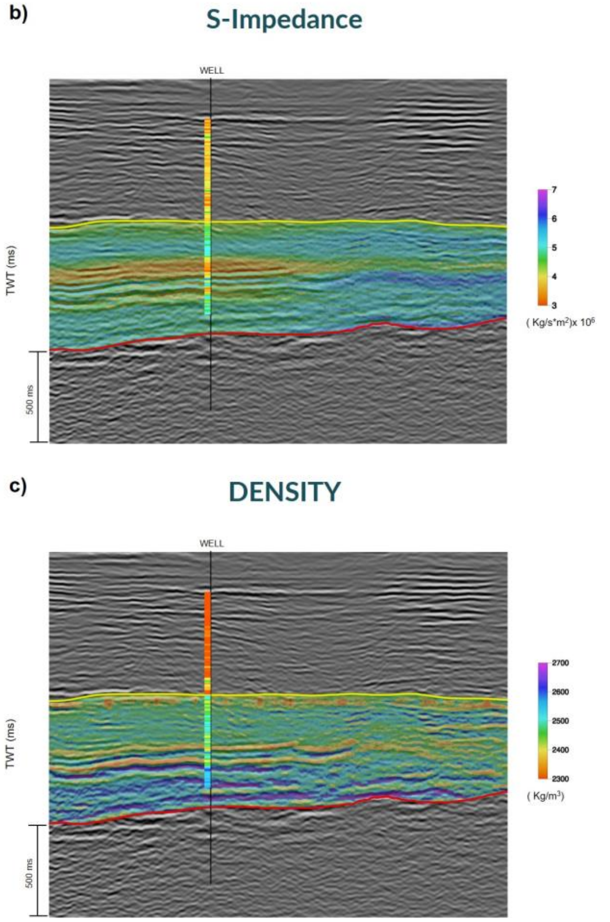


***Figure 9** – The sections represent the absolute elastic parameters P-impedance (a), S-impedance (b) and Density (c), derived from AVA-FWI inversion compared to well logging, superimposed on the amplitude seismic.*

Conclusions

Despite all the challenges of applying a Prestack AVA-FWI Elastic Inversion on onshore seismic data, the workflow combining seismic preconditioning and elastic inversion was effective for extracting quantitative information from the noisy dataset. The seismic data enhancement tools increased the signal-to-noise ratio and the fidelity of the AVO curves providing benefits for seismic interpretation and reservoir characterization. In addition, the recovery of the amplitudes during the preconditioning stage was a decisive step in obtaining reliable estimates for all three elastic parameters Vp, Vs, and density from AVA-FWI inversion, adding value to assist production development and reservoir properties delineation.

Acknowledgments

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