Gabor Deconvolution as Preliminary Method to Reduce Pitfall in Deeper Target Seismic Data

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Abstract. Anelastic attenuation process during seismic wave propagation is the trigger of seismic non-stationary characteristic. An absorption and a scattering of energy are causing the seismic energy loss as the depth increasing. A series of thin reservoir layers found in the study area is located within Talang Akar Fm. Level, showing an indication of interpretation pitfall due to attenuation effect commonly occurred in deeper level seismic data. Attenuation effect greatly influences the seismic images of deeper target level, creating pitfalls in several aspect. Seismic amplitude in deeper target level often could not represent its real subsurface character due to a low amplitude value or a chaotic event nearing the Basement. Frequency wise, the decaying could be seen as the frequency content diminishing in deeper target. Meanwhile, seismic amplitude is the simple tool to point out Direct Hydrocarbon Indicator (DHI) in preliminary Geophysical study before a further advanced interpretation method applied. A quick-look of Post-Stack Seismic Data shows the reservoir associated with a bright spot DHI while another bigger bright spot body detected in the North East area near the field edge. A horizon slice confirms a possibility that the other bright spot zone has smaller delineation; an interpretation pitfall commonly occurs in deeper level of seismic. We evaluates this pitfall by applying Gabor Deconvolution to address the attenuation problem. Gabor Deconvolution forms a Partition of Unity to factorize the trace into smaller convolution window that could be processed as stationary packets. Gabor Deconvolution estimates both the magnitudes of source signature alongside its attenuation function. The enhanced seismic shows a better imaging in the pitfall area that previously detected as a vast bright spot zone. When the enhanced seismic is used for further advanced reprocessing process, the Seismic Impedance and Vp/Vs Ratio slices show a better reservoir delineation, in which the pitfall area is reduced and some morphed as background lithology. Gabor Deconvolution removes the attenuation by performing Gabor Domain spectral division, which in extension also reduces interpretation pitfall in deeper target seismic.

1. Introduction

In its ideal form, seismic trace should be a product of convolution between subsurface reflectivity and source waveform. However, seismic data recorded is a filtered result of subsurface reflectivity during the wave propagation process infiltrating layers of lithology below the earth surface. The filter is a combination between the source wavelet used during seismic acquisition along with the attenuation effect during seismic wave propagation through various lithology condition. Anelastic attenuation process during seismic wave propagation is the trigger of seismic non-stationary characteristic. An absorption and a scattering of energy are causing the seismic energy loss as the depth increasing. In extension, attenuation leads to a loss in amplitude as well as frequency content of seismic data, or known as characteristics to the non-stationary condition of seismic data. As a function of energy loss, a deeper target of seismic data would suffer the most of attenuation effect. It is a common knowledge that a reservoir located deep below earth surface such as Talang Akar Fm. is difficult to delineate due to the poor seismic resolution and its typical thin reservoir grouped as a sand/shale crossover. The exploration challenge is how to optimize and quite possible, to enhance the seismic resolution in order to show a better imaging of hydrocarbon reservoirs through a conventional seismic data.

Responding to this challenge, preliminary conditioning process is the next sensible step to do in order to enhance seismic data resolution before it is being used as an input for interpretation or advanced reprocessing workflow. Deconvolution is a common method to boost seismic resolution during seismic data processing. Several assumption takes place in deconvolution process. One of them is assuming a stationary condition in seismic data. This assumption allows the method to simply calculate one deconvolution operator value applied to the whole seismic data. For many years, this assumption serves a great approach to the real condition, albeit it is still quite not right to apply stationary assumption for a seismic data which almost always identified as having a variability in time, commonly known as non-stationary characteristic.

Gabor Deconvolution is a non-stationary deconvolution method done in frequency domain. It is a modification of Wiener method for a non-stationary condition such in seismic data. Using Lamoureux window, Gabor Deconvolution divides the non-stationary seismic trace into a smaller localized signal called Gabor Wave Packets. By doing Fourier analysis in each localized packages, Gabor Deconvolution allows a non-stationary filtering in seismic trace represented by the various deconvolution operator generates for one seismic trace [1]. On its wake, Gabor Deconvolution also estimates Spectrum of Propagating Wavelet, which is a combined function between source wavelet and the attenuation occurred during propagation. The purpose of applying Gabor Deconvolution as preliminary conditioning method is to restore the amplitude and frequency content diminished by attenuation effect in order to get the seismic data recorded resembling its' supposed to be subsurface condition. In extention to the enhancement of seismic data resolution, Gabor Deconvolution could also reduce the interpretation pitfall of deeper target seismic data caused by amplitude failure in identifying Direct Hydrocarbon Indicator (DHI).

2. Methodology

Deconvolution is a main step in seismic data processing which aim to enhance the data resolution and produce an adequate imaging of subsurface condition through a conventional seismic data. The main purpose of deconvolution is to compress source waveform effect in the data recorded so the output seismic would increase its vertical resolution and resemble the actual reflectivity series. The most common method of deconvolution is Wiener Deconvolution and Predictive Deconvolution that categorized into statistical deconvolution. Both assumes seismic data as a stationary signal, in which against the fact that seismic data is a non-stationary signal that suffers energy loss as the depth progressed. Gabor Deconvolution, which works in frequency domain, is a deconvolution method that approach this non-stationary condition of seismic data using a modification of Wiener method.

Dennis Gabor in 1946 brought up the idea of applying Fourier analysis in partition sense [2]. A series of non-stationary seismic trace is divided into smaller signal packet which was localized by a certain window. The smaller signal packet is called Gaussian Wave Packet, localized using Gaussian window at first attempt by the inventor. Later on, Gabor Deconvolution has developed further by Margrave et. al. [3] and now using Lamoureux window to decompose trace into Gabor Wave Packet. The Lamoureux window provides a more localized signal due to its zero condition on each end point whereas the Gaussian window only decays to each end point; never touches zero condition.

Gabor Deconvolution has a similar workflow to the conventional seismic deconvolution process since it is basically only a modification in which the process is applied to a smaller and more localized signal. Fourier transform is applied to each Gabor Wave Packet making it possible to do a non-stationary filtering to seismic trace. Hyperbolic time-frequency smoothing is applied to seismic in

Gabor Spectrum in order to estimate Spectrum of Propagating Wavelet, or in the conventional deconvolution model known as the deconvolution operator. The source waveform as well as attenuation effect are removed by doing a spectral division between seismic in Gabor Spectrum and its deconvolution operator. This leaves only the estimated reflectivity in its output making it suitable to apply in a case where seismic energy loss clouding the real amplitude response commonly found in deeper level of seismic data.

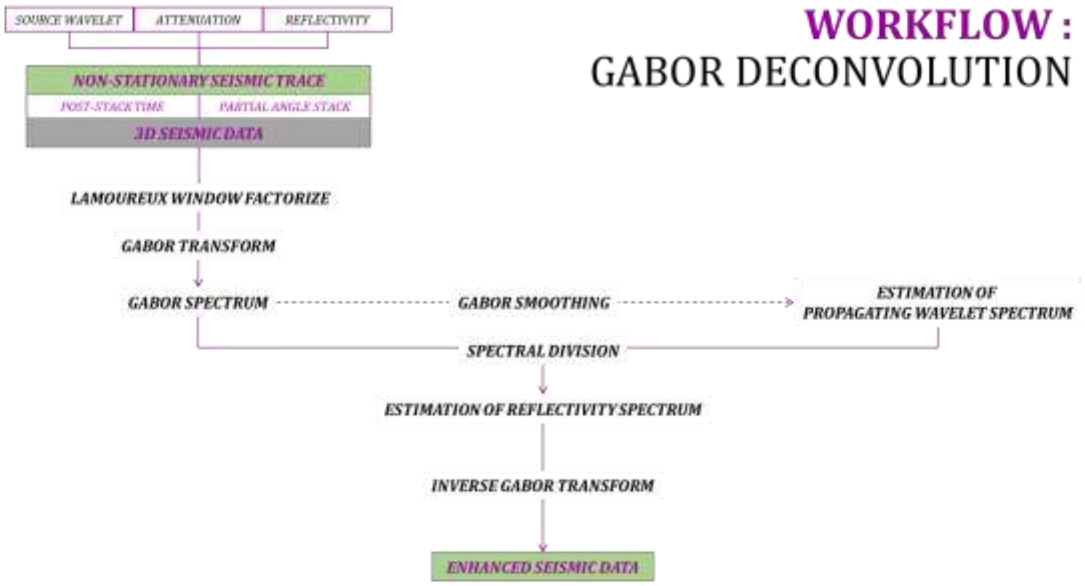

Figure 1. Gabor Deconvolution workflow (after Margrave et. al., 2002)[3] in general sense.

Gabor Deconvolution consists of several step that illustrated in Figure 1. The basic steps are choosing width of stationary packets from non-stationary seismic signal, converting seismic data into Gabor domain, generating a Gabor slice using a moving Lamoureux window, smoothing the seismic data in Gabor domain into the Spectrum of Propagating Wavelet, deconvolving initial seismic signal by doing a spectral division with the propagating wavelet, and performing time-variant filter if necessary. The algorithm is quite complex, but has a benefit of approaching a solution for non-stationary seismic data.

The final goal of this study is to compare the benefit in applying Gabor Deconvolution as a preliminary conditioning method before embarking a further interpretation and advanced reprocessing workflow. The enhanced seismic data would be used as an input of workflow for detecting a possible reservoir delineation in deeper target seismic. A production report and log sensitivity analysis confirm that the reservoir in this study area associated with a bright DHI area and small value of Vp/Vs Ratio. Vp/Vs Ratio volume would be obtained from Aki-Richard Partial Stack Inversion algorithm formulated by Supriyono [4]. P&S-Reflectivity volume would be created from Partial-Angle Stack Seismic Data (Near & Far) and inverted to P&S-Impedance using Model-Based Hard Constraint method. The output Vp/Vs slice from the enhanced seismic data and the initial seismic data would then be compared to showcase the reduction of reservoir area caused by amplitude pitfall commonly found in deeper target seismic data.

3. Results & Discussions

Gabor Deconvolution is evaluated as seismic enhancement method focusing on its reducing pitfall benefit in deeper target seismic data. The data used in this study is a marine seismic data with proven hydrocarbon reservoir status in Talang Akar Fm. The study will focus on PRAIA sequence which is part of Talang Akar Fm showing a sand/shale crossover with the producing level located exactly in the middle of its thickness. LJB-01 is an oil-producing well associated with a bright-spot DHI and a small Vp/Vs Ratio value. Gabor Deconvolution has proven could resolute a local fluid trap problem of the upper level reservoir and minimize the attenuation effect when it is applied to Post-Stack Seismic Data as shown in Figure 2 [5]. Referring to previous study, Gabor Deconvolution in Ensemble Mode produces a more stable output and preserves the DHI well. Gabor Deconvolution Ensemble Mode would be used as preliminary conditioning method for Partial Angle Stack Seismic data in this study.

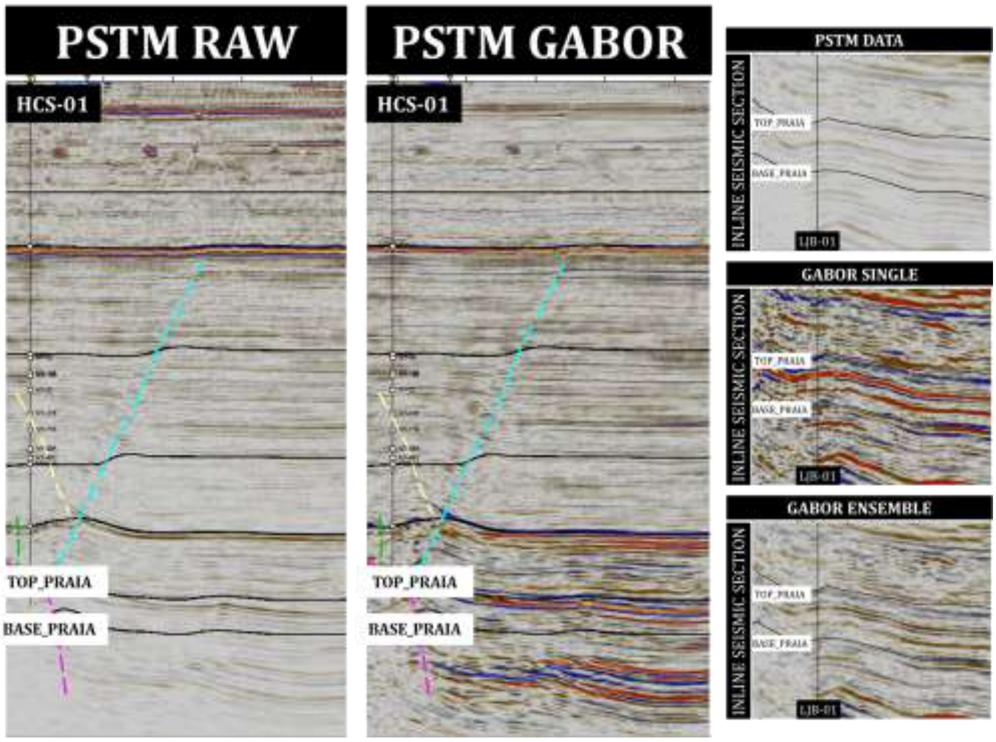

Figure 2. Previous study had researched the benefit of Gabor Deconvolution as preliminary conditioning technique applied to Post-Stack Seismic Data. Gabor Deconvolution in Ensemble Mode has proven to be a suitable technique for seismic enhancement purpose in this study area [6].

There are several main parameter that influence the quality of output result during Gabor Deconvolution process. To find a suitable value, a parameter optimization is a must step to undergo in which we could determine the most effective value for each parameter and also find the best value combination between all parameters. The optimization is analyzed for half-width analysis window, window overlap factor, slope exponent for window, and corridor width for hyperbolic smoothing. The optimization focuses on the Lamoureux window parameter and a smoother parameter to determine the attenuation function. As the input data in this study consists of two different datasets, Near Angle Stack and Far Angle Stack, the Gabor Deconvolution parameter would be slightly different from one another. Figure 3 shows a comparison between initial Partial Angle Stack datasets with its enhanced result. Notice that after applying Gabor Deconvolution, the number of event between TOP_PRAIA and BASE_PRAIA is increasing. Several thin layers could be resolute. It is a given because the tuning thickness has been lowered by Gabor Deconvolution. The initial seismic data has 19,899 m tuning thickness and the enhanced seismic data has a 14,225 m tuning thickness while the thinnest reservoir layer in PRAIA sequence is around 15 m [6]. The most noticeable thing, after Gabor Deconvolution, the amplitude level around PRAIA level has been restored to be as strong as a shallow level of seismic data. It is one of indication that the attenuation effect has been reduced from the initial seismic data. If we take a look at the frequency content and amplitude content of the enhanced seismic datasets as shown in Figure 4, it has proven that Gabor Deconvolution method could restore the amplitude and frequency content of seismic data back resembling the supposed to be stationary condition. The initial Partial Angle Stack datasets has a decaying frequency content as well as an amplitude loss both in lower and higher side. After applying Gabor Deconvolution, the amplitude spectrums are back resembling the perfect boxcar and the frequency content appears in all time-frequency plot. The diminishing in frequency and loss in amplitude content are often the cause of DHI pitfall in deeper level seismic data.

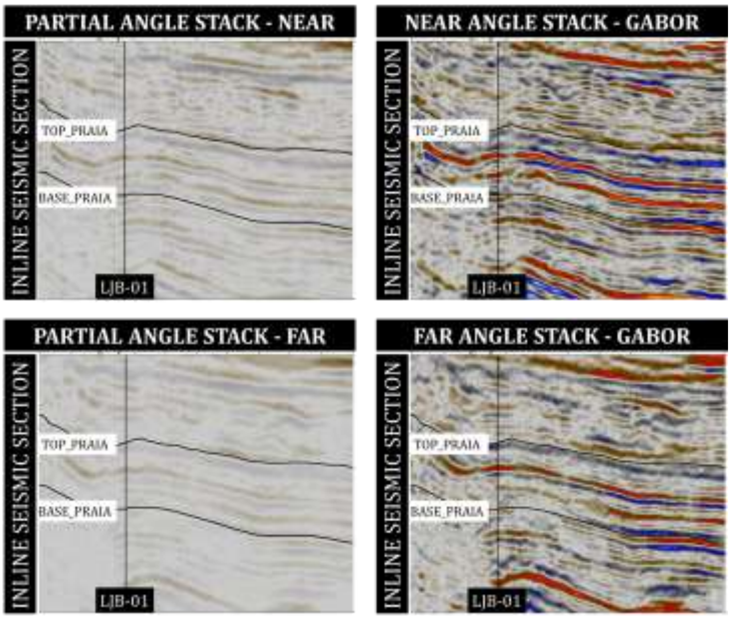

Figure 3. Comparison of seismic section in inline 211 around CDP well LJB-01. PRAIA sequence is located within Talang Akar Fm. Left side shows the initial Partial Angle Stack Seismic. Right side shows the enhanced datasets after applying Gabor Deconvolution as preliminary conditioning method.

Reservoir delineation would be analyzed through Vp/Vs Ratio maps with assistance from reflectivity volume. Vp/Vs Ratio is generated from Partial-Angle Stack Seismic datasets using Aki-Richard Partial Stack Inversion [4]. P&S Reflectivity volumes are produced from Partial-Angle Stack datasets by a least-square inversion of Zoeppritz Aki-Richard simplification for two fold datasets case as the Partial-Angle Stack data we use has only the near and far part. The formulation of reflectivity volume could be studied further in the reference research. Because the input for calculating the reflectivity volume is in fact two different datasets, we must ensure that the two has a similar amplitude and bandwidth level before joining the two together. This purpose is achieved through a spectral matching step. Then P&S Reflectivity are calculated as an input for Model-Based Hard Constraint seismic inversion to produce P&S Impedance. Gabor Deconvolution shows its benefit in increasing the correlation between estimated impedance from inversion result and hard-data impedance from well-log as shown in Figure 5. The crossplot shows that after applying Gabor Deconvolution, the data is more focusing around the red line and the scattered point is decreasing. The estimation error also reduces from 2588,04 to 2296,82 point.

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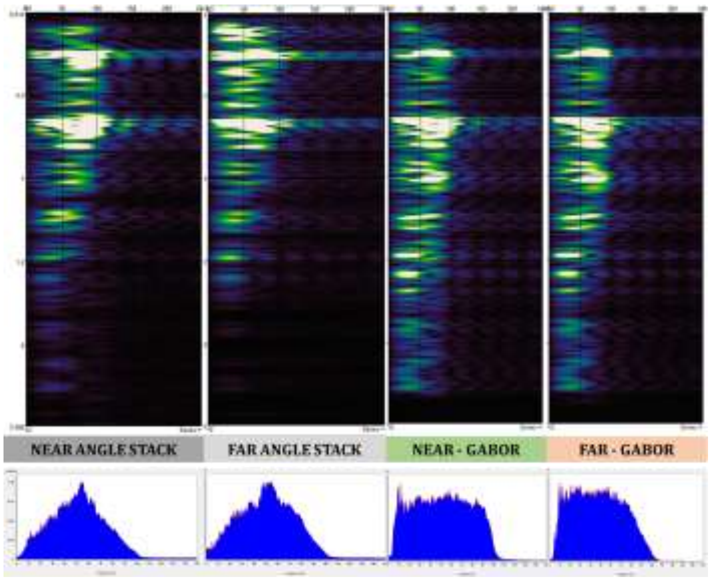

Figure 4. Frequency and amplitude content comparison between initial Partial-Angle Stack Seismic and the Gabor Deconvolution results. Above part shows time-frequency plots using Spectral Decomposition technique for a -10 to 10 Hz window. Below part shows amplitude spectrum with amplitude in Y-Axis and frequency in X-Axis.

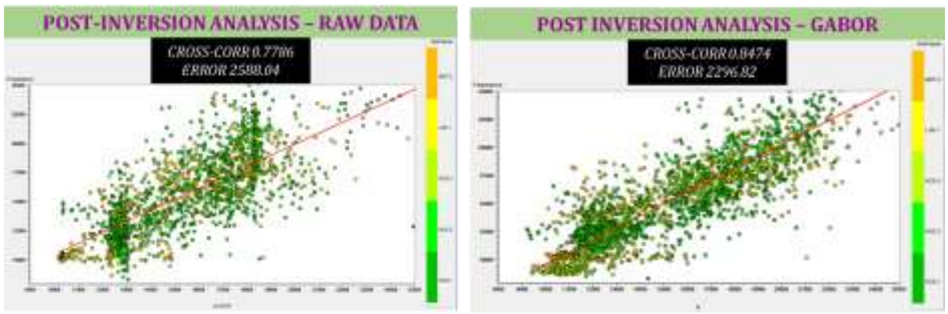

FIGURE 5. Comparison of post-inversion analysis before and after applying Gabor Deconvolution.

The inversion result shows that after applying Gabor Deconvolution, P&S Impedance along with Vp/Vs Ratio section could resolute more event compared to the initial seismic. The enhancement result is strongly appointed around the black arrow area where several thin layer appears above the arrow (Figure 6). The arrow itself points at a single thick layer in initial seismic data but the layer turns out to be a doublet layer that could be separated into two different layers after applying Gabor Deconvolution. The pitfall found in this exact layer. This layer is the producing layer in PRAIA sequence with LJB-01 proven as oil-producing well. Post-Stack Seismic Data (PSTM) associates this oil saturated layer with a bright spot area [6]. To the north-east area, the PSTM data shows a similar bright spot that potentially saturated with oil. The PSTM slice maps a vast bright spot area while the Partial-Angle Stack Data shows that the bright spot is actually smaller. The horizon slice of enhanced seismic result after Gabor Deconvolution shows a more detailed reservoirs delineation (Figure 7). Area above the arrow in initial seismic data detects as a bright zone and its produced Vp/Vs Ratio also shows a small value indicated the area as a hydrocarbon saturated zone. If the development decision is based from these information, that above the arrow area would be choose as the next well location. But when we analyze the map after Gabor Deconvolution enhancement, that area actually contains a blotchy saturated area surrounded by non-saturated zone with the saturated intensity is yellow to green. The most possible hydrocarbon location is indicated by a red area in Vp/Vs Ratio slice. This is the amplitude pitfall that could mislead the development plan if the decision solely relies on DHI. Even if we don't produce Vp/Vs Ratio slice as a justification for development plan, the enhanced seismic after Gabor Deconvolution itself could already help to delineate the reservoir better. So by using Gabor Deconvolution as a preliminary method for further interpretation or advanced reprocessing workflow, the pitfall and interpretation uncertainties could be reduced further.

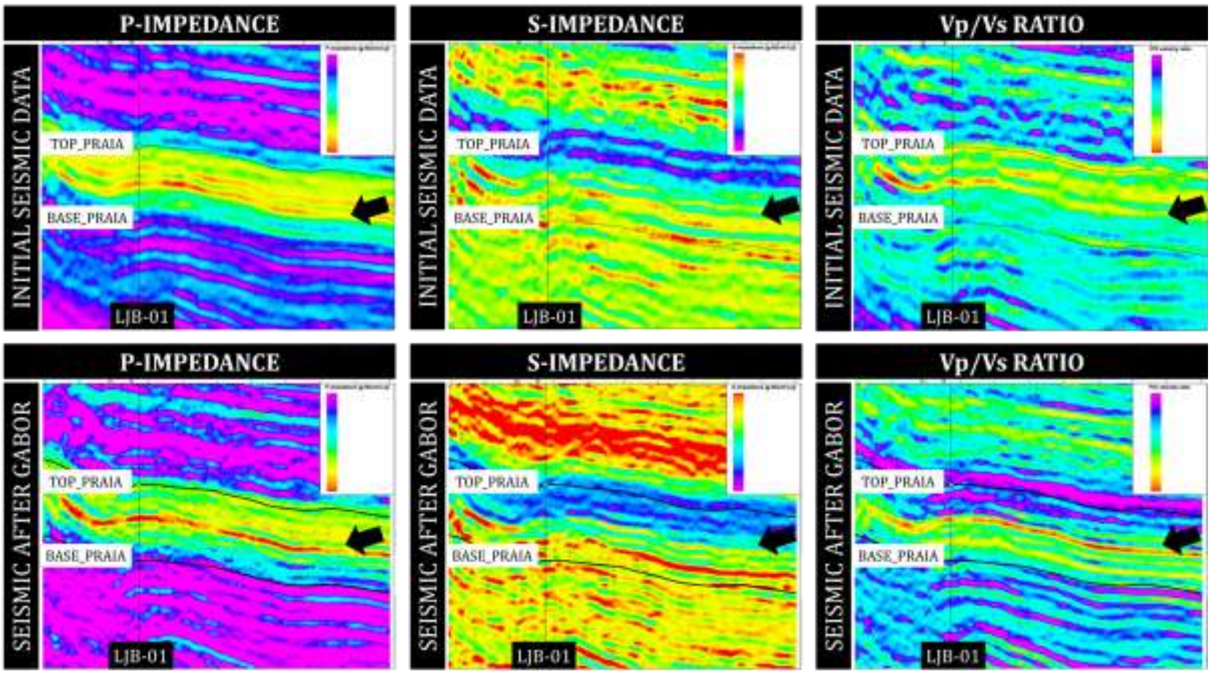

Figure 6. Output comparison of Aki-Richard Partial Stack Inversion. Upper side shows P-Impedance, S-Impedance, and Vp/Vs Ratio of initial seismic data. Lower side shows the results from enhanced seismic after applying Gabor Deconvolution. Black arrow shows oil-producing layer in PRAIA sequence.

4. Conclusions

A loss in amplitude and frequency content caused by attenuation effect are proved to increase interpretation uncertainty in deeper level of seismic data. Amplitude failure in detecting hydrocarbon indicator is a common pitfall occurred in area with strong attenuation influenced such as Talang Akar Fm. Without any delicate treatment, the amplitude could lead to a bizarre development plan assisted by a false accuracy of reservoir delineation. Gabor Deconvolution as a preliminary conditioning method has benefit in enhancing seismic imaging and vertical resolution in deeper target seismic data by removing attenuation effect that cause a non-stationary condition in seismic data. The enhanced seismic from Gabor Deconvolution could recover a thin layer and separate the doublet within PRAIA sequence in Talang Akar Fm for this study area. Gabor Deconvolution has proven an aid to reduce a possible development risk by delineating the reservoir in more detailed manner even before the advanced reprocessing method is applied. By using Gabor Deconvolution as preliminary conditioning method, the result of further reprocessing workflow, such as Aki-Richard Partial Angle Stack Inversion, could achieved even more satisfying justification to determine hydrocarbon delineation in deeper target seismic data.

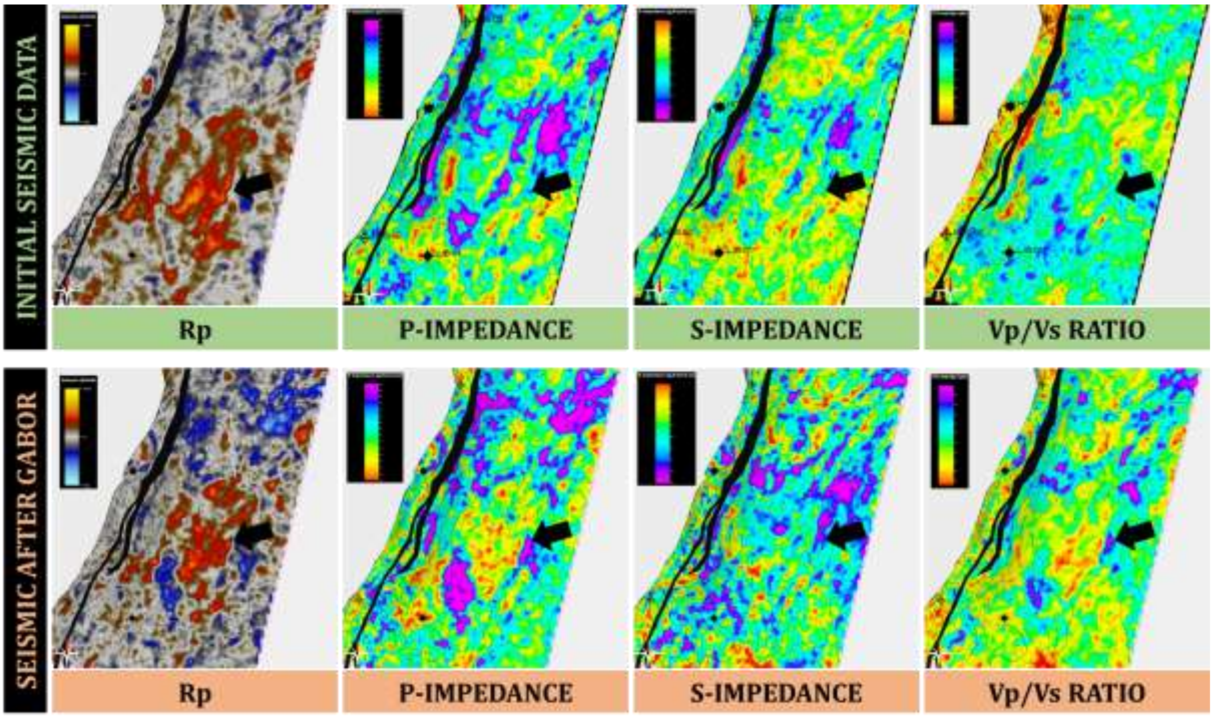

Figure 7. Horizon slice of oil-producing layer in PRAIA sequence. Upper side shows Reflectivity P, P-Impedance, S-Impedance, and Vp/Vs Ratio of initial seismic data. Lower side shows Reflectivity P, P-Impedance, S-Impedance, and Vp/Vs Ratio of enhanced seismic result after applying Gabor Deconvolution as preliminary conditioning method. Black arrow shows the possible hydrocarbon delineation from well LJB-01 area.

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