Ground roll attenuation and improvement of velocity analysis using SVD filtering in the frequency domain and L_p deconvolution

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Abstract

In this work, we apply the SVD adaptive filtering in the frequency domain and the iterative method of deconvolution based on L_p norm to attenuation of the ground roll and improvement of velocity analysis. The SVD decomposition separates the signal and the noise in different eigenimages bands. When the eigenimage is selected in an appropriate way is possible to preserve the seismic reflections without the noise. The SVD adaptive filtering in the frequency domain is applied within the frequency zone of the ground roll, it is performed by the difference between the original spectrum and the SVD spectrum. The iterative method of deconvolution based on L_p norm performs well even when with the mixed-phase wavelet and it uses the causal and anti-causal filter, overcoming the results with conventional WL deconvolution. The SVD filtering combined with L_p deconvolution were tested in the seismic line of the Tacutu Basin. The results show that the combined methods allow to attenuate the ground roll, improve the velocity analysis, and to improve the quality of the stacked seismic.

Introduction

The ground roll is a kind of noise frequently in land-based seismic acquisitions. It has low frequency, low velocity and high amplitude. Occurs in the central zone of shot gather, hiding the seismic reflections and lowering the signal/noise ratio. The attenuation is important to seismic processing because will easy the velocity analysis, and increasing the quality of the seismic section.

The singular value decomposition (SVD) is an useful method to seismic data processing applied as coherence filter. Increase the signal/noise ratio through of separation of different bands of eigenimages, by selecting correctly ones to the reconstruction of the filtered seismic data the seismic information without the noise can be obtained. There are many works that use the SVD method to seismic processing improvement, combined with deconvolution, to the ground roll attenuation and improvement of velocity analysis (Freire, 1986; Bekara and Van der Baan, 2007; Porsani et al., 2009). The SVD adaptive filtering is performed by the central trace which is selected within of subset traces that form the moving window. This trace is reconstructed with only the first eigenvalue that represents the seismic reflections. In the frequency domain can be applied to a frequency band, the result is a characteristic content of frequency relative to the band chosen. The filtering is applied by the difference between the original frequency spectrum and the SVD spectrum. In this way the SVD filtering works in the frequency band of the ground roll attenuating this noise.

The deconvolution is important to the seismic data processing. When applied increases the temporal resolution, compress the wavelet and the reflection events are well detailed. Recovers the reflectivity function by the convolution of the seismic trace with the inverse filter. Helps the tracking of layers in the subsurface and facilitates the seismic interpretation. The conventional deconvolution is performed by using Wiener-Levinson (WL) approach which uses minimum-phase wavelet and random reflectivity. Therefore the filter is causal and the autocorrelation function can be obtained by the autocorrelation of the seismic trace. The minimum-phase wavelet is more difficult to happens in real situations, because in general occurs the mixed-phase wavelet, and thus the results are not better (Porsani and Ursin, 2000). The iterative deconvolution based on L_p norm does not consider the minimum-phase wavelet, it shows better result than the conventional deconvolution. The L_p deconvolution uses the mixed-phase wavelet and it is performed by causal and anti-causal filter (Melo, 2002).

This work has as objective to apply the SVD filtering in frequency domain to the pre-stack data to attenuating the ground roll, and as well to improve the velocity analysis. Thus with the post-stack data to combine the filtered stacked section with L_p deconvolution. This way the combined methods increase the quality of the stacked section.

SVD Filtering

The SVD adaptive filtering is an useful method for seismic data processing. It separates the signal and the noise in different eigenimages band. The first eigeimages record the important information, for example the reflections, and the last ones are responsible for the noise. Using just the first eigenimages is possible to recover the seismic data without the noise. The result improves the quality of the seismic data. The SVD method performs the seismic data matrix decomposition $\mathbf{X}$ as shown the equation below:

$$\mathbf{X} = \mathbf{U}\Sigma\mathbf{V}^T, \quad (1)$$

where:

- $\Sigma = diag\{\sigma_1, \cdots, \sigma_M\}$, is the singular value matrix $(N_t \times M)$ and $\sigma_1 \geq \cdots \geq \sigma_n \geq 0$;
- $\mathbf{U} = [\mathbf{u}_1 \cdots \mathbf{u}_M]$, is the eigenvector matrix $(N_t \times N_t)$ relative to time;
- $\mathbf{V} = [\mathbf{v}_1 \cdots \mathbf{v}_M]$, is the eigenvector matrix $(M \times M)$ relative to space.

The SVD filtering approach takes for each seismic trace of the seismic section a subset M of the neighbor traces and performs the SVD decomposition to this subset, and reconstructs partly the resulting filtered trace $\tilde{\mathbf{x}}_j$, which is expressed as:

$$\tilde{x}(t, a_j) = \sum_{k=1}^{K} \sigma_k u_k(t) v_k(a_j), \quad (2)$$

where each parcel of the sum is relatives to eigenimage, t is relatives to time and a_j describe the record amplitude by the receptor j. The filtered trace $\tilde{x}(t, a_j)$ is constructed by the K eigenvectors. Small values of K have greater spacial coherence, preserving the horizontal events and attenuating the vertical events, as for example the ground roll (Porsani et al., 2009).

The SVD adaptive filtering in the frequency domain (SVD_{fd}) is applied to the frequency band of the data spectrum. First we take the data to the frequency domain using the fast Fourier transform. Then we apply the SVD_{fd} filtering resulting in the SVD spectrum with only the first eigenimage. The filtered spectrum is the difference between the original spectrum and the SVD spectrum. Finally we apply the inverse fast Fourier transform to the filtered data. The SVD_{fd} has three parameters: the number of traces (L) that construct the moving window; the number of times (N) that we take the difference between the original spectrum and the SVD spectrum; and the frequency band to perform the filtering. The filtering attenuates the resulting spectrum which is without the frequency band of ground roll.

The SVD_{fd} filtering to the ground roll attenuation is performed between the average frequency where the noise occurs and the maximum frequency of the data. The filtering moving to all the frequency and the shift between the filtered spectrum and the original one is not discontinuous. So this filtering has better results that the applied in Lima (2013), because the filtered spectrum is more smooth (Lima, 2014).

L_p Deconvolution

The iterative of deconvolution based on L_p norm is a method that does not depend on the minimum-phase wavelet and it performs well with wavelet mixed-phase. This deconvolution works with causal and anti-causal filter, and allows to collapse the wavelet even when it does not have the minimum-phase (Porsani and Ursin, 2000; Porsani et al., 2001; Melo, 2002). The predictive error function for the signal is defined by a function based on L_p, given by the equation:

$$Q(\mathbf{a}^+, p) = \sum_{t=0}^{m+n} \left\{ \left[e_t^2 \right]^{1/2} \right\}^p, \quad (3)$$

where:

- $\mathbf{a}^+$ is the vector with the causal filter;
- p is the exponent norm L_p;
- m correspond to the number of samples of the traces x_t;
- n correspond to the number of filter coefficients;
- e_t are the samples of the deconvolved trace in the time t.

In the Eq. (3) a nonlinear function $f(\mathbf{a}, p, t) = (e_t^2)^{p/4}$ can be defined. Expanding $f(\mathbf{a}, p, t)$ using Taylor series around the current model $\mathbf{a}_k$, and disregarding terms of second order we have:

$$f(\mathbf{a}, p, t) \cong \tilde{f}(\mathbf{a}, p, t) = f(\mathbf{a}_k, p, t) + \left[\frac{p}{2} (e_t^2)^{p/4-1} e_t \right] \frac{\partial e_t}{\partial \mathbf{a}} \bigg|_{\mathbf{a}_k} (\mathbf{a} - \mathbf{a}_k), \quad (4)$$

where $f(\mathbf{a}, p, t)$ is now a linear function.

The Eq. (4) can be written by a matrix form:

$$\tilde{\mathbf{f}}_p = \mathbf{f}_{kp} - \mathbf{F}_{kp}\mathbf{X}\Delta\mathbf{a}. \quad (5)$$

To solving the Eq. (5) we need to find the $\Delta\mathbf{a}$. The solution quadratic function $\tilde{Q}(\mathbf{a}, p) = \tilde{\mathbf{f}}_p^T \tilde{\mathbf{f}}_p$ will result in the vector $\Delta\mathbf{a}$, when minimized the quadratic form. The filter coefficients can be updated by the relation $\mathbf{a}_{k+1} = \mathbf{a}_k + \Delta\mathbf{a}$.

The equations are relative to the deconvolved trace with the causal filter $(1 \quad \mathbf{a}_k^T)$. The same approach can be performed with the anti-causal filter $(\mathbf{a}_k^T \quad 1)$.

Methodology

The seismic processing was performed in two steps. The raw data was processing in the first step. In the second step the SVD filtering in the frequency domain was applied, the velocity analysis was repeated and the L_p deconvolution was applied in the filtered stacked section. Figure 1 display the flowchart of processing.

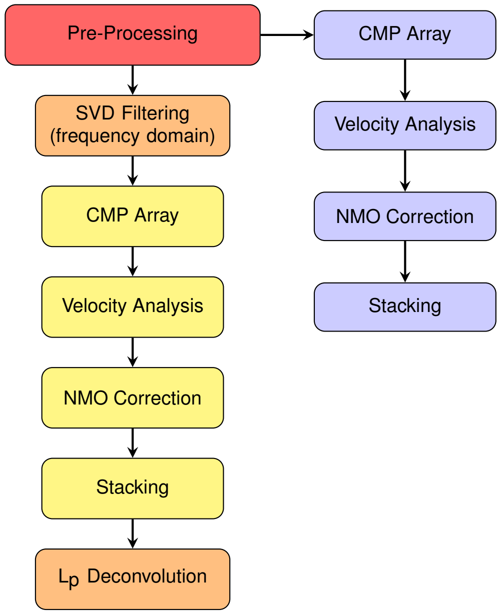

Figure 1: Flowchart of processing.

Results

The seismic data used was the seismic line 50−RL−90 of the Tacutu Basin. Figure 2a shows the original shot gather with the ground roll (in the red line), the presence of the noise hides the reflections in the central zone. Figure 2b shows the filtered data with SVD adaptive filtering in the frequency domain with the parameters L=25, N= 20 and with frequency band of $7-125$Hz. Figure 2c shows the residue that is the difference between of the original and filtered data, this result display essentially the ground roll and demonstrates the effectiveness of the SVD filtering in the frequency domain.

Figure 3 shows the amplitude spectrum of the shot gathers. The filtered spectrum shows that the SVD filtering performed directly in the ground roll zone, but does not annihilate all the spectrum and important informations preserved.

Figure 4a shows the velocity spectrum of the original data and the Figure 4b shows the velocity spectrum of the SVD filtered data which compared to the original spectrum shows more coherence points because the ground roll was removed and the reflections enhanced. As consequence the velocity analysis can be easier with the filtered data, and the quality of the stacked section increased.

Figure 5 shows the original stacked section. Figure 6 the stacked section with SVD filtering in the frequency domain, this filtered stacked section display better quality compared with the original one. We can see that the seismic reflections have better lateral continuity and were enhanced. This method also increase the number of reflections. Figure 7 shows the combined method of the SVD filtering in the frequency domain and the L_p deconvolution $(p = 1.3$ and filter of $n = 1$ coefficient). The result with deconvolution improved definition of the reflections. The red rectangle demarcates the detail to the Figure 8. Figures 8a, 8b and 8c show, respectively, the detail of original stacked section, the stacked section with SVD filtering and with SVD filtering and L_p deconvolution combined. We can see that the methods increase the horizontal resolution of the reflections and improve the identification of the reflected seismic events.

Conclusions

The application of the SVD adaptive filtering in the frequency domain was effective in noise attenuation, acting directly in the frequency band of the ground roll. It allows us to improve the velocity analysis and the continuity of the reflected events in the stacked section. The results show reflectors with better resolution and lateral continuity. The iterative deconvolution based on L_p norm compress the seismic wavelets allowing more precise identification of the reflectors. The attenuation of the ground roll by combining both methods was quite effective, increased the signal/noise ratio in the seismic stacked section compared with the original seismic stacked section.

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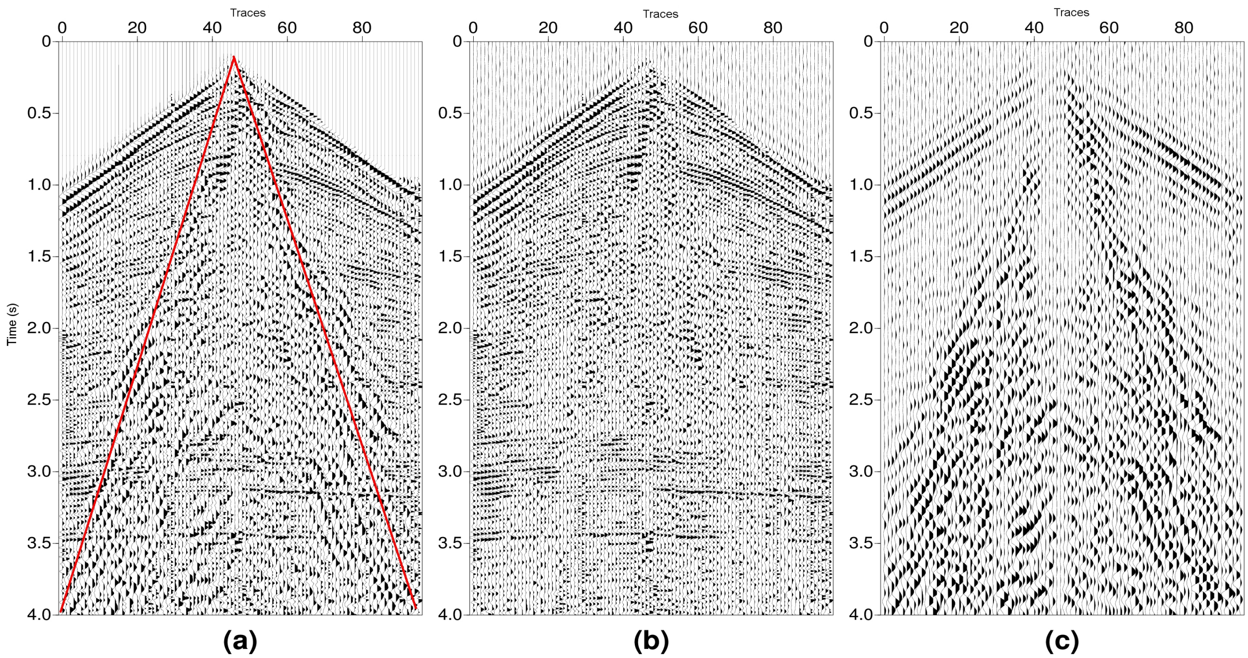

Figure 2: Original shot gather in (a), with SVD$_{fd}$ filtering in (b), residue in (c).

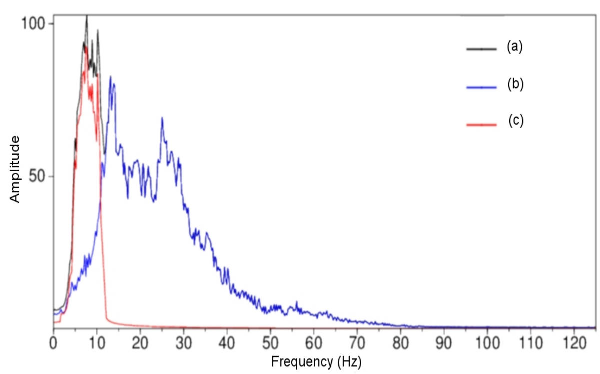

Figure 3: Amplitude spectrum: Original shot gather in (a), with SVD$_{fd}$ filtering in (b), residue in (c).

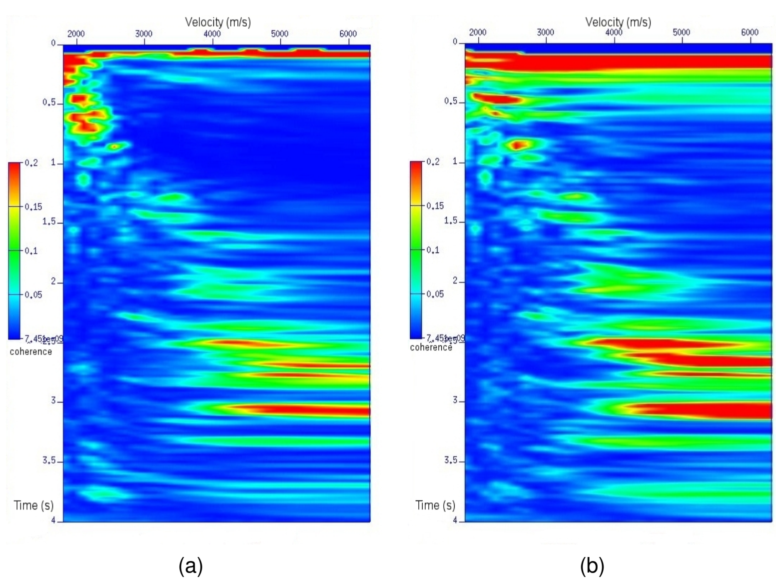

Figure 4: Original velocity spectrum in (a), with SVD$_{fd}$ filtering in (b).

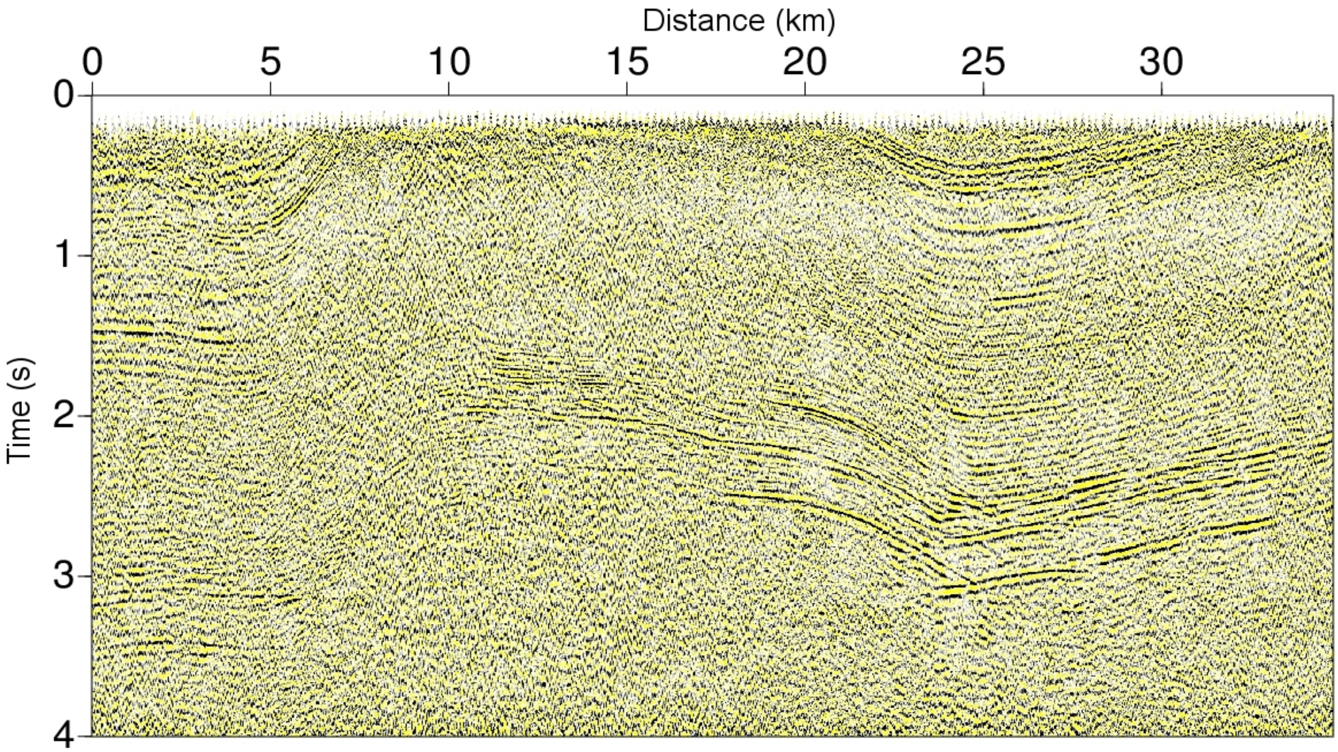

Figure 5: Original stacked section.

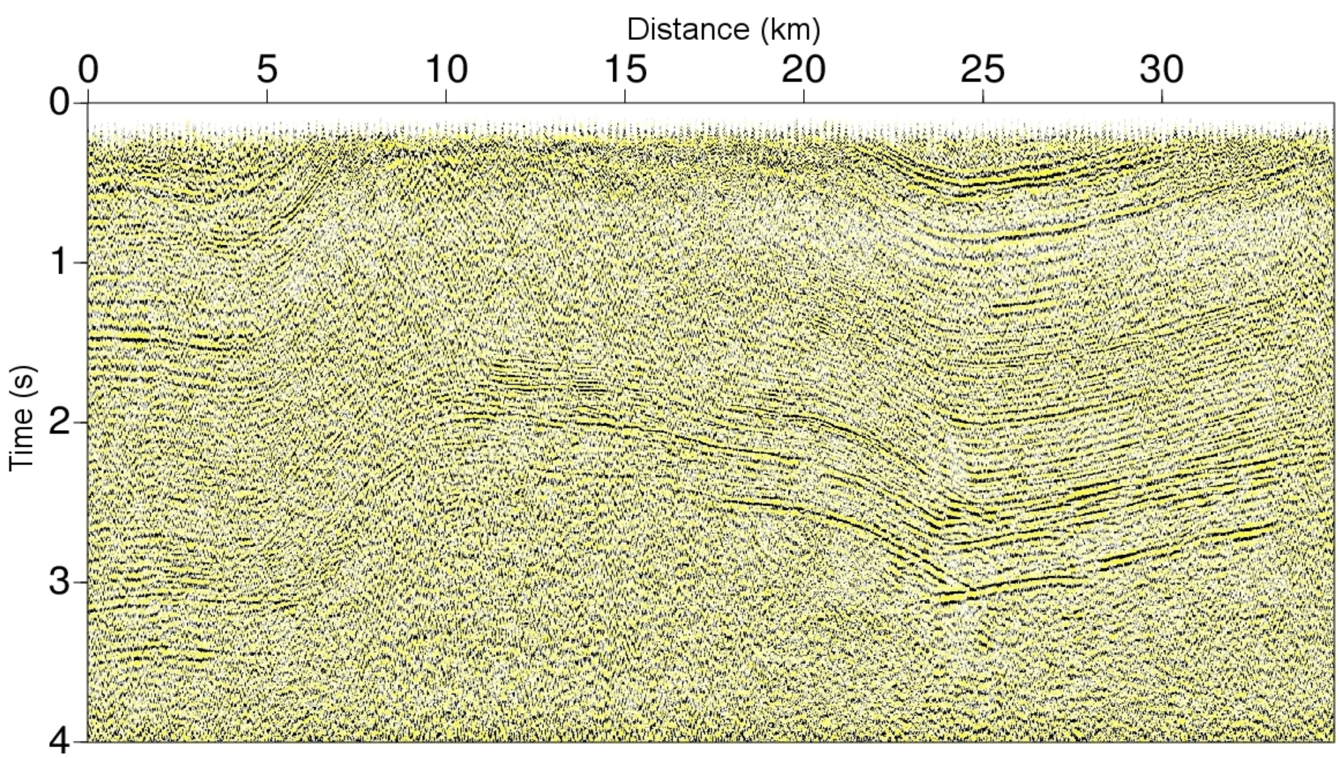

Figure 6: Stacked section with SVD_{fd} filtering.

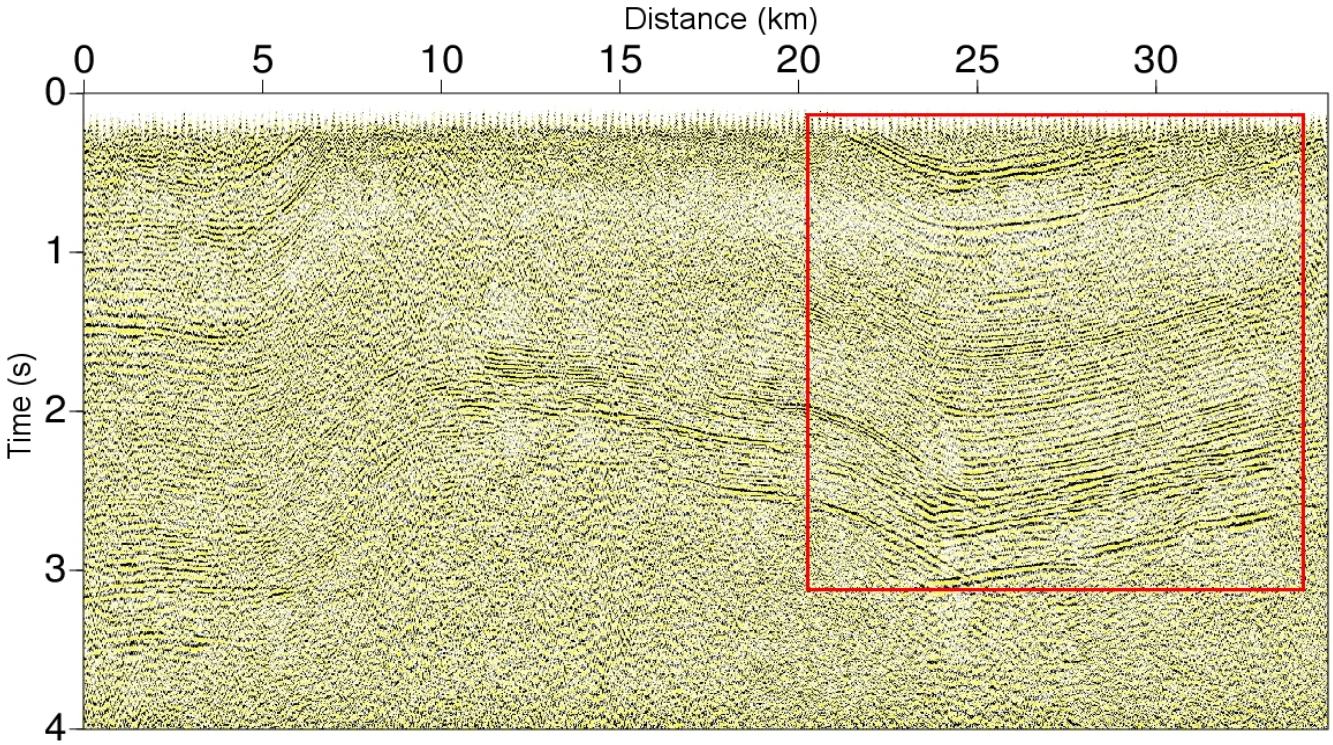

Figure 7: Stacked section with SVD_{fd} filtering and L_p deconvolution.

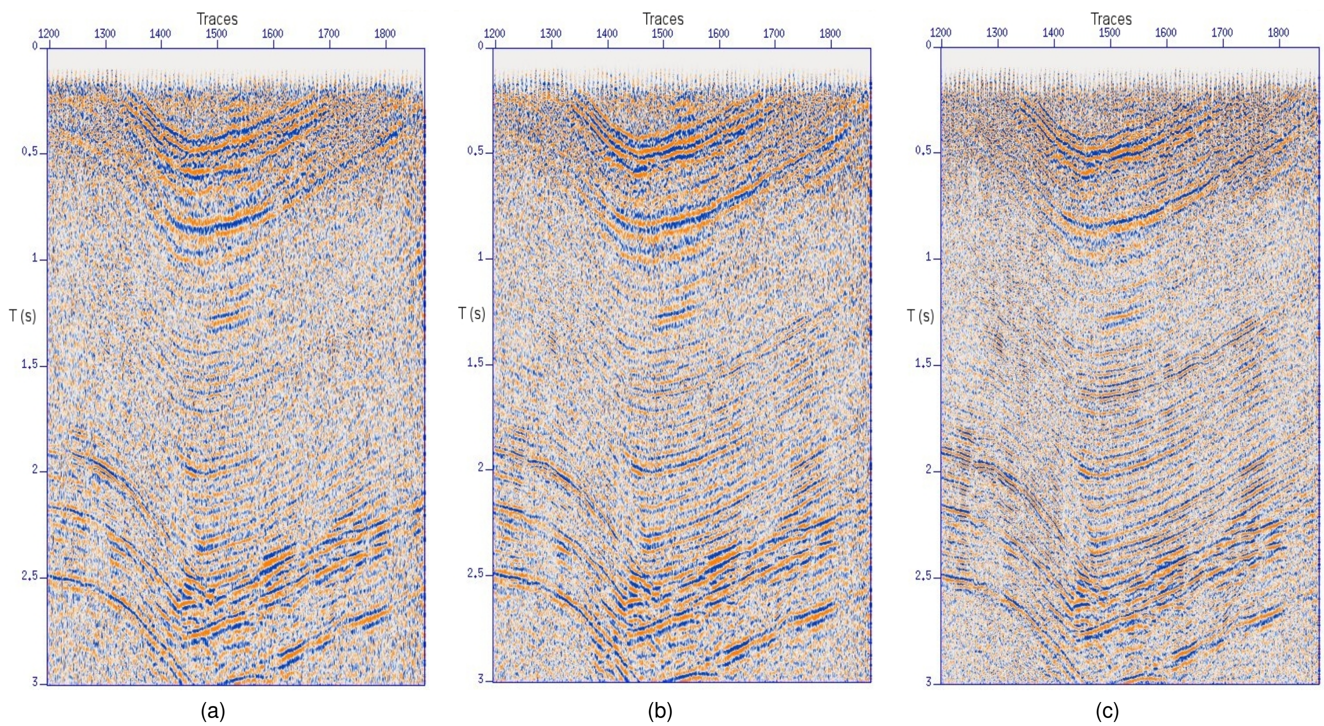

Figure 8: Detail of the stacked section original in (a), with SVD_{fd} filtering in (b), with SVD_{fd} filtering and L_p deconvolution in (c).