Comparison of f-k and SVD filtering in the processing of a land seismic data.

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Abstract

The paper aims to present a two-dimensional land seismic processing, involving two flowcharts, ranging from the pre-processing to the stage of post-stack migration. The flowcharts differ mainly in the filtering stage, through by different streams, wherein the first using a frequency filter (f-k filter) and the second with a spatial coherence filter (SVD filter).

Introduction

Seismic processing consists of a series of treatments applied to seismic reflection data, and the choice of each treatment and their parameters can be crucial in the imaging of geological subsurface structures (Yilmaz, 2001). The filtering step is one of the highlights in this work, and the main purpose is the analysis between two filters in different ways; one passing through f-k filter, and the other through SVD filter.

The f-k filter (frequency by wave number domain) allows selection regions according to slope of events. Therefore, it becomes effective for ground-roll attenuation. The ground-roll is a linear noise with a high inclination, very common in land data, formed by the spread of Rayleigh surface wave, with low frequency (5 to 15 Hz), low speed and high amplitude.

The SVD filtering (Singular Value Decomposition) is a filter based on spatial coherence that aims on improving continuity and position of reflectors, on relied on the SVD decomposition, which also results in attenuation of different noises (Freire, 1986; Bekara & van der Baan, 2007; Porsani et al., 2010).

Survey informations

Over an area of intracratonic basin Tacutu (Brazil), the seismic reflection survey consisted of 90 shots, with 96 geophones active every shot, using symmetrical split-spread arrangement, where the distance between shots was 200 m, and between geophones 50 m. The maximum coverage of CDP is 12 and the chosen haul was 2500-150-0-150-2500 m. The total recording time was 4 s using a sampling interval of 4 ms.

CMP processing

The performed CMP processing used the package Seismic Unix, with the assistance of GêBR platform, from the pre-processing phase, setting geometry and editing features, to the processing itself, with: filtering, deconvolution, CMP organization, velocity analysis, NMO correction, stacking and post-stack time migration.

Geometry, edition and trace mute

Saved initially in SEGY format, it was necessary the conversion of the data to the proper format Seismic Unix package, then checked the geometry information already present in the header, and your agreement to the actual survey. The addition of some other keys as CDP (common depth point) and offset also it was important. Figure 1a shows the seismogram of shot 19 without any processing (raw data).

Once the assembly geometry, there were applied some editions in amplitude trace, in order to highlight the region where the possible reflections occur, and reduce random noise (non-seismic source used). The editions consisted of: limit the data to 3.5 s; apply mute amplitudes in less time than the direct wave; eliminating noisy traces (due to problems of acquisition); and an apply AGC. The Figure 1b shows the result of these steps.

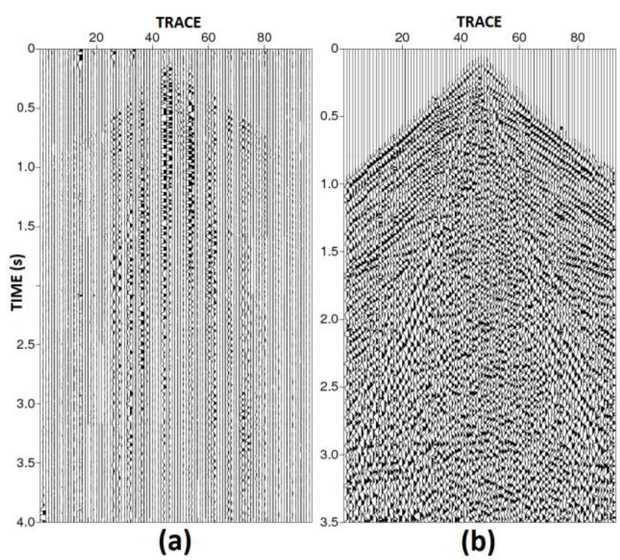

Figure 1: Seismograms of shot 19: (a) raw data; (b) after mute and trace edition.

F-k filter

After editing and mute of trace amplitudes, commonly in seismic processing flow chart, it recommends some kind of filtering. The first filter used was f-k filter, which is a two-dimensional filter defined in the frequency domain obtained by Double Fourier Transform:

$$F(k,\omega) = \int_0^\infty \int_0^\infty f(x,t) e^{ikx - i\omega t} dt dx \qquad (1)$$

Plotted the f-k spectrum, regions shall be chosen where amplitudes will pass by eliminating, attenuating and storing (see Fig. 2). The classic method to define such regions should be slope calculation, defined by the ratio f by k ($slope = f/k$). The selected slopes were 0.16, 0.08, 0.038 and 0.03. Briefly, points closer to axis k represent, in seismograms, horizontal events (reflectors), and the further away from axis k represent inclined events, such as the ground-roll. Figure 9a represents the outcome of filter.

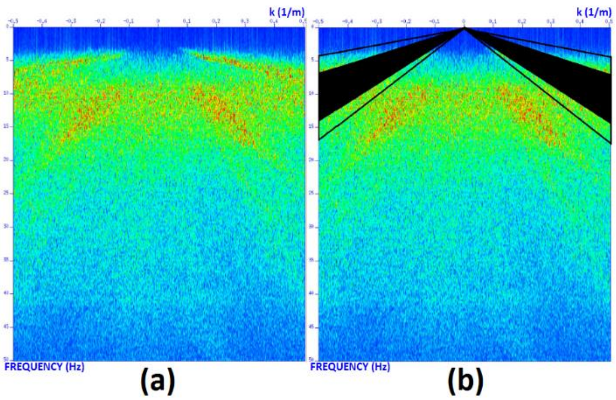

Figure 2: (a) panel of the frequency spectrum (f versus k); (b) frequency spectrum showing the regions that will be attenuated (within the hollow triangles) and eliminated (under the black triangles).

SVD filter

With intention of analyzing the best filter to this specific case, the data was submitted to SVD (Singular Value Decomposition) filtering. The SVD filter has as base the spatial coherence; therefore, is required prior NMO correction. The algorithm steps that perform the SVD filtering consist, basically, of (Porsani et al., 2010):

- Selecting the subset of M traces immediate neighbors to each trace $d(t, x_j)$ of section;
- Decomposition in singular values (SVD), according to the matrix equation:

$$\boldsymbol{D} = \boldsymbol{U\Sigma V^T} \quad (2)$$

- SVD filtering application itself, by the sum:

$$d_j = \sum_{k=1}^{M} \omega_k \boldsymbol{u}_k v_k \quad (3)$$

- Partial Reconstitution of trace using only k eigenimages:

$$\tilde{d}(t, x_j) = \sum_{k=1}^{K} \sigma_k u_k(t) v_k(x_j) \quad (4)$$

After SVD filtering applied, Fig. 9c illustrates its result, besides the Figure 3 showing the average amplitude spectrum of original and post-filtering data. Comparing Fig. 9a to 9c is apparent the greater sharpness of reflection hyperbole on seismograms after SVD filter, showing the power of the method for reducing noise (especially the ground-roll) and increasing reflections continuity.

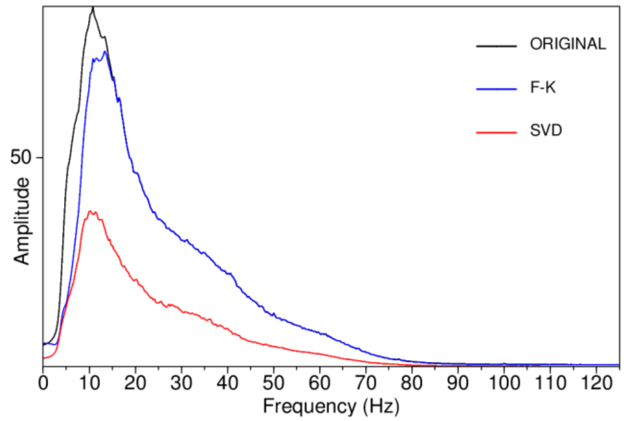

Figure 3: Average amplitude spectrum (frequency versus amplitude) of: original data (black curve), stacked section with f-k filter (blue curve) and with SVD filter (red curve).

Trace deconvolution (Wiener-Levinson filter)

Deconvolution means the act of neutralizing a previous convolution or convolution operation with the inverse filter. During deconvolution process, it seeks to estimate an inverse filter, which results in a seismic trace with very similar characteristics to impulse (Dirac delta), increasing resolution of reflectors, attenuating multiple reflections and greatly decreasing noise level.

The deconvolution process along with the estimate of inverse filter passed by the procedure known as Wiener-Levinson filter (Levinson, 1947), which, from seismic trace, found the autocorrelation function, and solve its normal equations system, thus obtain the predictive filter coefficients. Convolving seismic traces to predictive filter (Wiener-Levinson inverse filter), the sections with deconvolved traces are obtained. The result of applying this procedure is present in Figures 9b (after f-k filter) and 9d (after SVD filter).

Velocity analysis and NMO correction

After applying the frequency filters and deconvolution procedure, the line went through a reorganization of its traces, from the common shot gathers domain to domain of common midpoint families (CMP). Then, the data passed by a procedure known as supergather or common offset stack, which consists into stack traces with same offset value for increasing data coverage, thus allowing obtain a more reliable velocity analysis later.

The supergather consisted into fifteen groups, containing 51 CDPs each group. It has used for velocity analysis through Semblance method, which points with greater coherence were chosen, representing the most likely regions of reflection hyperbole apices. After generated the velocity for time spectrum, the points that better determined NMO velocities, and consequently better flatten reflectors, were selected (as exemplified by CMP 140, shown in Figures 4 and 5, on line with f-k and SVD filter, respectively). Sorted with the selected points, two files containing the velocity fields were created (i.e., the estimated velocity of layers in each section point), illustrated in Figure 6. The velocity fields was used to normal moveout correction on line organized into CMP families illustrated by NMO correction simulation of CMP 140 of supergather after f-k (Fig. 7) and SVD filter (Fig. 8).

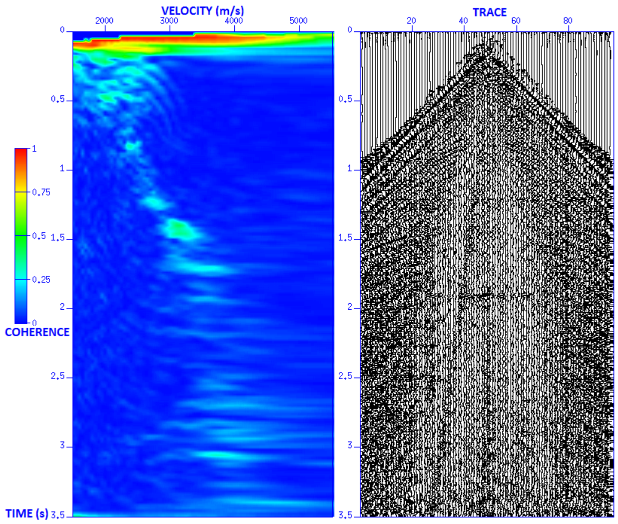

Figure 4: Interface of Semblance in the velocity analysis made to CMP 140 of supergather after the f-k filtering.

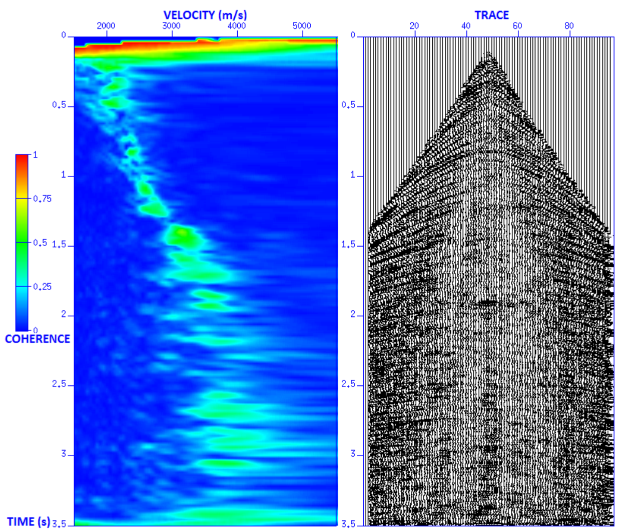

Figure 5: Interface of Semblance in the velocity analysis made to CMP 140 of supergather after the SVD filtering.

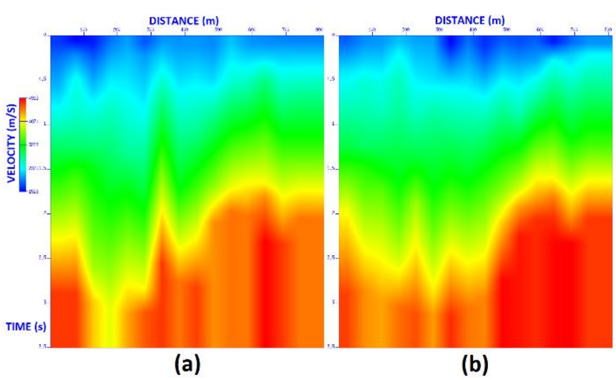

Figure 6: Velocity field of line with: (a) f-k filter and (b) SVD filter.

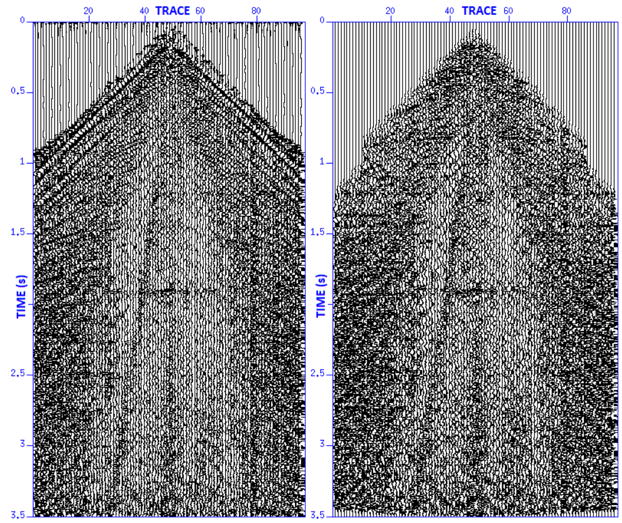

Figure 7: Simulation of the NMO correction to the CMP 140 of the supergather after the f-k filtering. Data before (left section) and after (right section) correction.

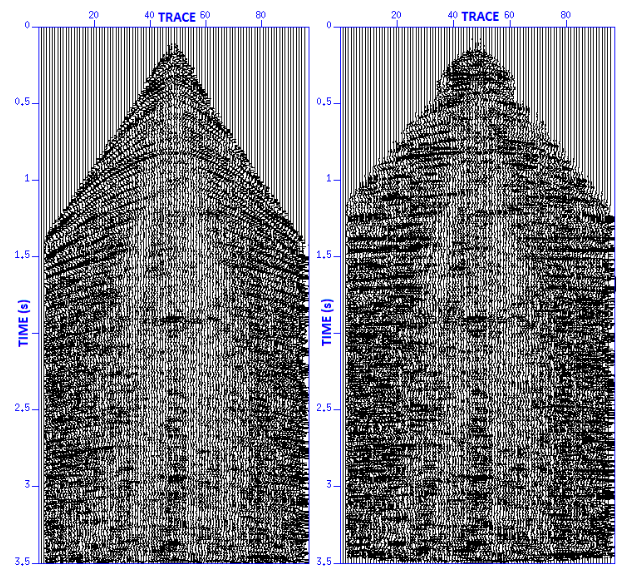

Figure 8: Simulation of the NMO correction to the CMP 140 of the supergather after the SVD filtering. Data before (left section) and after (right section) correction.

Stacking

After NMO correction, the data passed by stacking process, which adds (superimposes) CMPs with same coordinates. This process represents the great success of CMP processing, considerably increasing the signal/noise ratio, approaching reflectors to geological reality. Figures 11 and 12 show the resulting of stacking, by variable density plotting.

Time migration

After the stage of stacking, the sections were submitted to a trapezoidal bandpass filter, which attenuates the region between 5 Hz and 12 Hz and between 55 Hz and 70 Hz, allowing the passage without modifications of frequencies between 12 Hz and 55 Hz, and eliminate the others.

In order to fix the position of reflectors, the data passed by stage of migration, with section still presented in time. The migration chosen was phase-shift, which, in frequency domain, allows vertical velocity variations. Through shifts in phase, it is possible to correct the position of some features and inclined reflections. Migrated sections illustrate the final stage of the processing in Figures 14 (with f-k filter) and 15 (with SVD filter). The line without any filter also was stacked (Fig. 10) and migrated (Fig. 13), with same velocity field found after the SVD filter, in order to analyses the total processing and compare filters.

Conclusions

Analyzing the resulting migrated sections, a significant improvement is remarkable in filtered section images (Figures 14 and 15) in comparison to raw migrated section (Fig. 13). Improvements occur mainly in continuity and amplitude of reflectors, especially between 1 s and 2.5 s.

The migrated section with SVD filter (Fig. 15) also allows better imaging of features, highlighting more reflections, than migrated section with f-k filter (Fig. 14).

Therefore, the SVD filter, with a more powerful algorithm, showed best results in processing carried out for the land seismic line of Tacutu Basin. It is noteworthy that still is possible an improvement in final migration, considering a more accurate velocity analysis, leading to a better smoothed velocity field, which not only improve stacking, but also data migration; such processes would benefit from a priori information about the physical properties of geological layers, among others aspects.

Acknowledgements

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References

Bekara, M. and Baan, M. V., 2007, Local singular value decomposition for signal enhancement of seismic data, Geophysics, 72, 59-65

Freire, S. L. M., 1986, Aplicações do método de decomposição em valores singulares no processamento de dados sísmicos. Tese de Doutorado, Universidade Federal da Bahia, Salvador, Brasil.

Levinson, N., 1947, The Wiener RMS (Root Mean Square) criterion in filter design and prediction. J. Math. Phys., vol. 25, 261-278.

Porsani, M. J., Artola, F. A. V., Silva, M. G. e Melo, P. E. M., 2010, Filtragem SVD aplicada à melhoria do rastreamento de horizontes sísmicos. Revista Brasileira de Geofísica, vol. 28, nº 3, 473-480.

Yilmaz, O., 2001, Seismic Data Analysis. Society of Exploration Geophysicists, Tulsa, U.S.A.

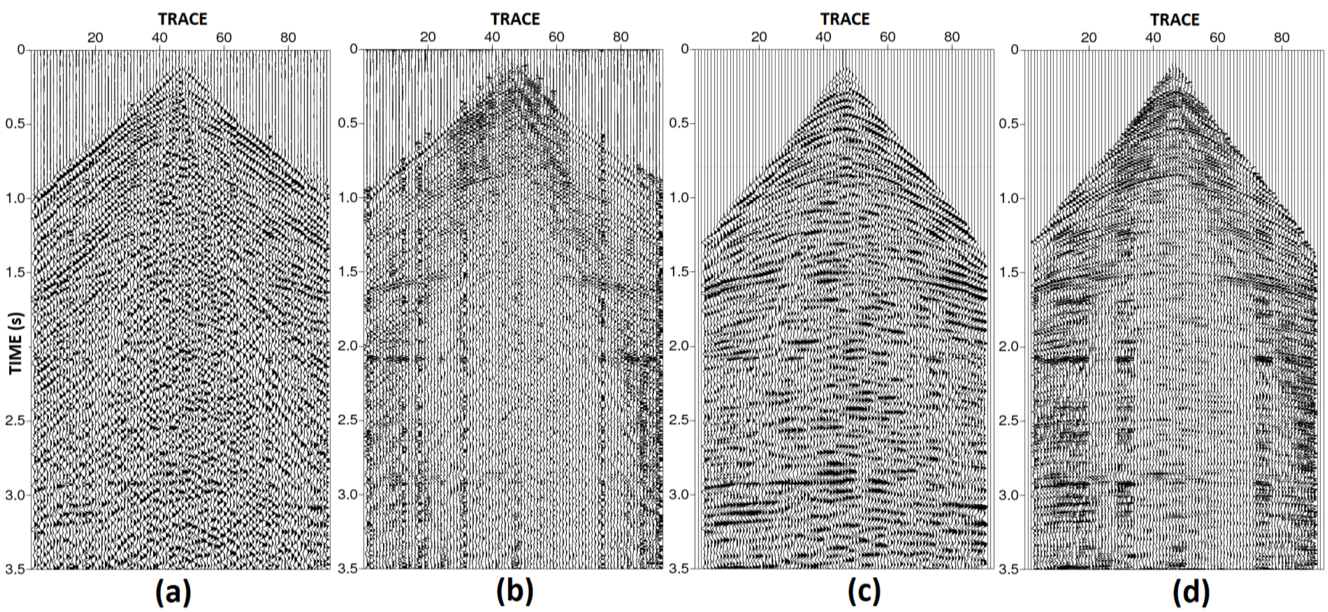

Figure 9: Seismograms of the shot 19: (a) after f-k filter; (b) after f-k filter and deconvolution; (c) after SVD filter & (d) after SVD filter and deconvolution.

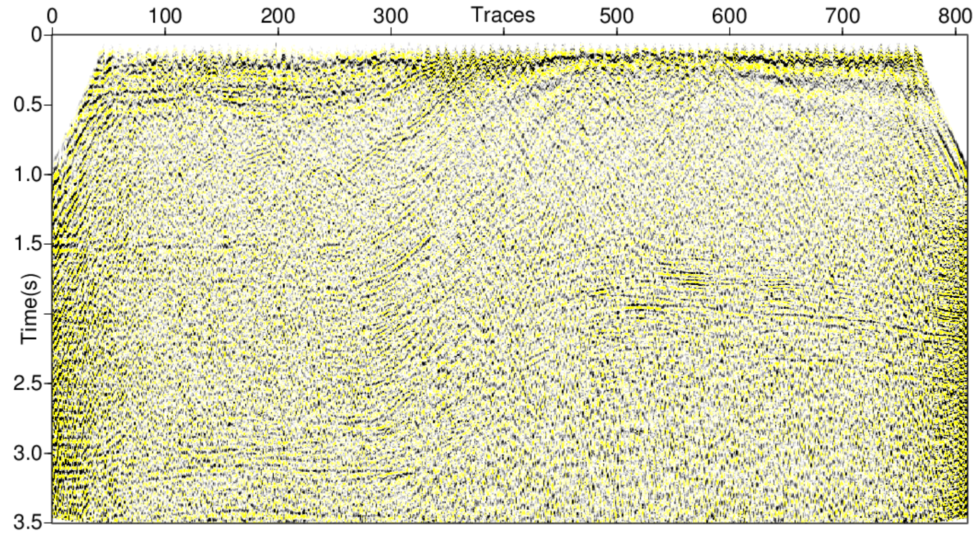

Figure 10: Raw stacked section.

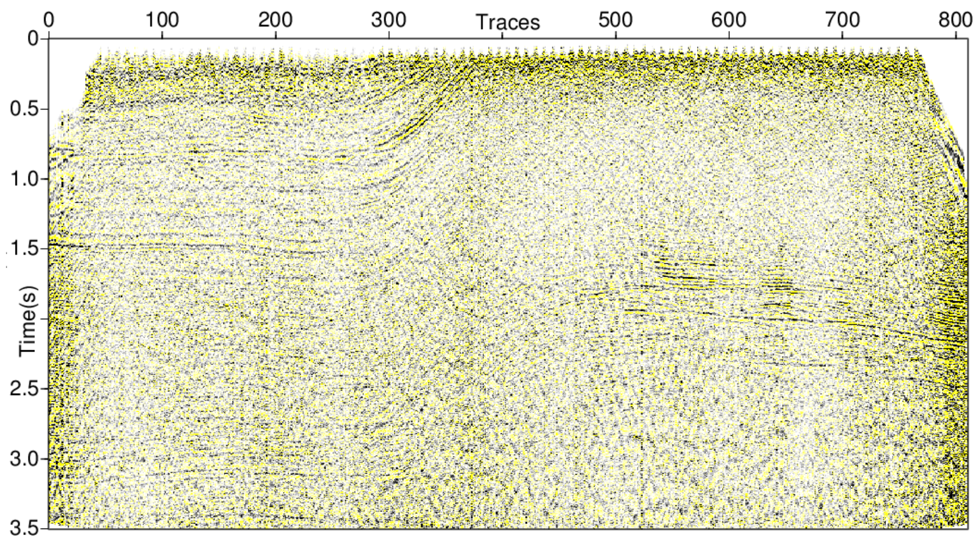

Figure 11: Stacked section after f-k filter and deconvolution.

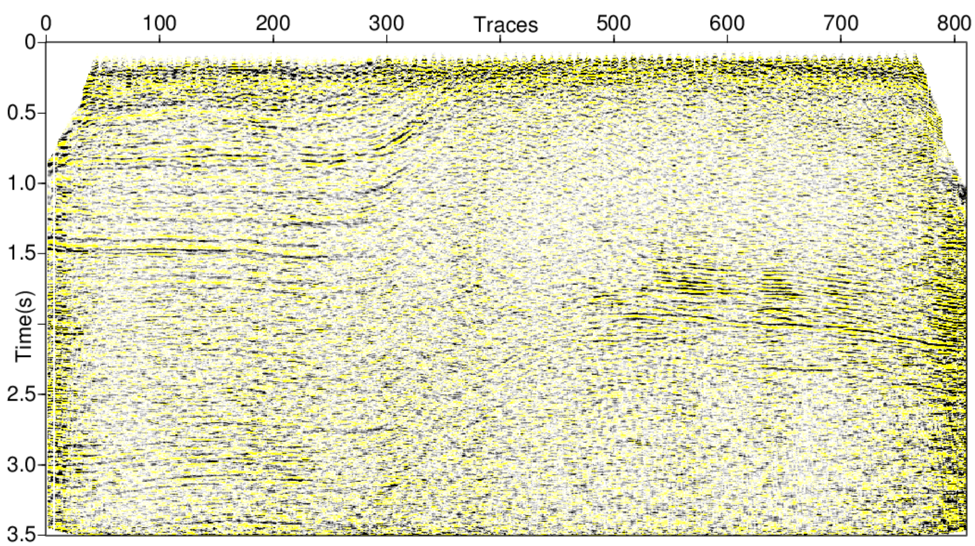

Figure 12: Stacked section after SVD filter and deconvolution.

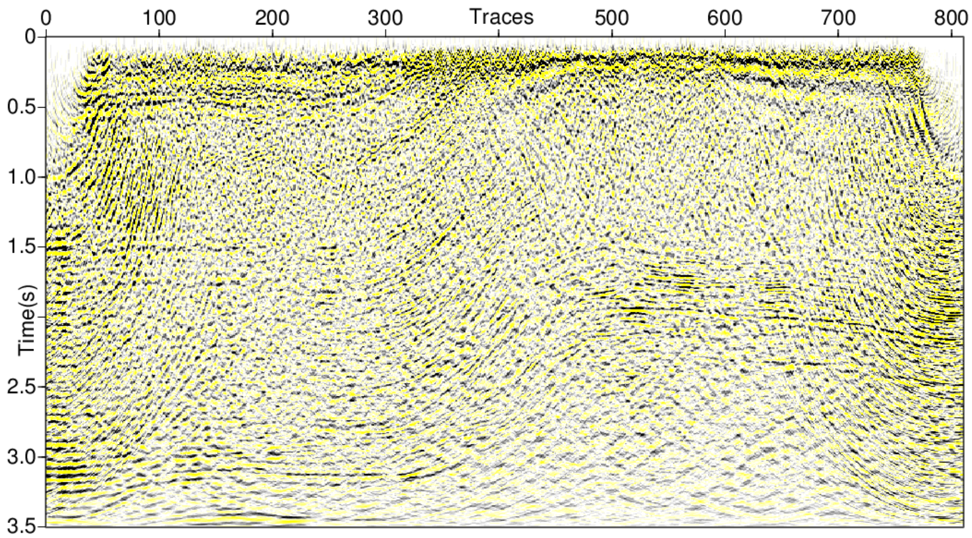

Figure 13: Raw phase-shift migrated section.

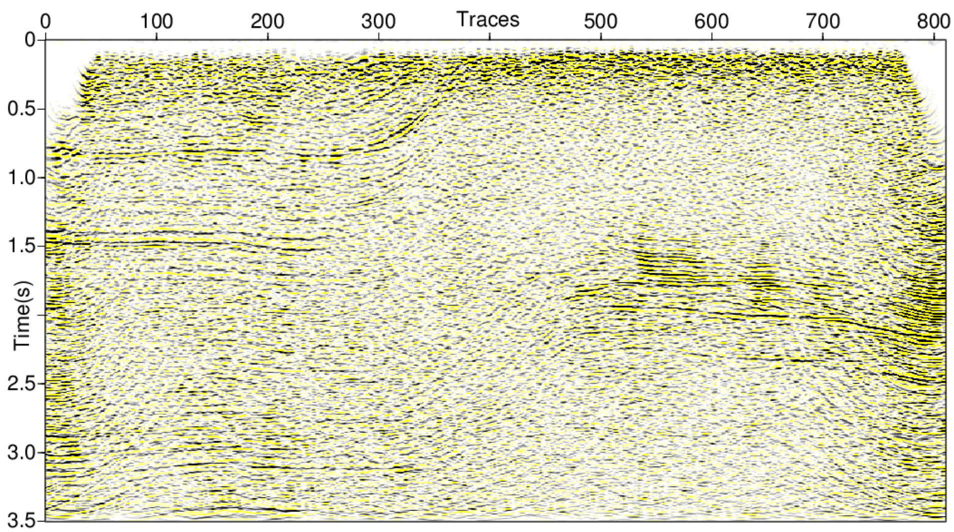

Figure 14: Phase-shift migrated section after f-k filter and deconvolution.

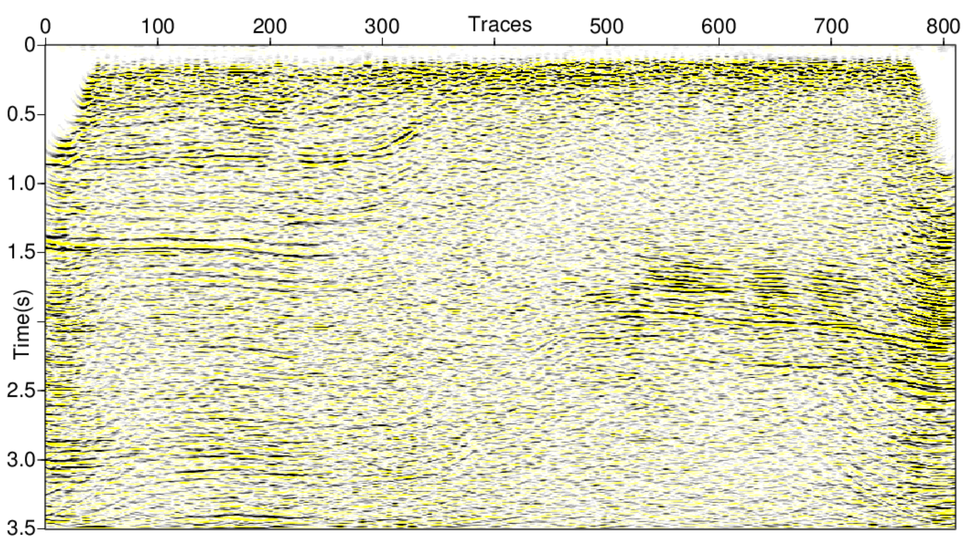

Figure 15: Phase-shift migrated section after SVD filter and deconvolution.