GC Identifying and Fixing Artifacts that Arise in Structure-Oriented Filtering*

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General Statement

In general, structure-oriented filtering suppresses random and cross-cutting coherent noise, leading to not only more effective horizon autotracking, but also subsequent improved attribute volumes. In general, the spectrum of random noise is white, with equal components at both low and high frequencies. Because the seismic signal tends to be band-limited, the signal-to-noise ratio deteriorates at both the low and high end of the spectrum. On unmigrated gathers, source-generated coherent noise such as multiples exhibits the same spectrum as the signal, while the spectrum of noise such as ground roll tends to be concentrated at the lower frequencies. Migration operator aliasing (remnants of migration ellipses that do not destructively interfere) appears as steeply dipping coherent artifacts that cut across reflectors of interest. Because these events are steeply dipping at angle θ from the horizontal, their spectrum is divided by $\cos\theta$, resulting in low apparent frequency artifacts. It is common practice in the processing shop to not only remove spikes in the data and apply mutes, but also to apply a final band-pass filter (say 8-120 Hertz) to remove extraneous artifacts in the data.

Because they are familiar with the geology, have access to well log control, and may be focused on improving the seismic resolution of a specific interpretation objective, interpreters are well qualified to apply additional conditioning to the data to either better balance the spectrum or the reject noise.

Mean, Median and Principal Component Filters

The simplest and the most familiar noise suppression filter is the mean filter and represents an arithmetic average of a given number of spatial samples, usually five or nine for 3-D data. When applied along structure, they are referred as “structure-oriented mean filters.” Iterative mean filters implemented by cascading or reapplying the filter to a previously filtered version of the data can provide further improvements, rejecting short wavelength noise. Unfortunately, fault and stratigraphic edges have a short wavenumber spectrum such that mean filters will smear discontinuities in the seismic data and thus are usually avoided. A structure-oriented median filter not only suppresses random noise, but also preserves lateral reflector discontinuities. This filter sorts samples from high to low values within the chosen aperture along the local dip and azimuth and replaces the amplitude of the central sample position with the median value of the amplitudes. Median filters are very effective at suppressing high-amplitude artifacts in the seismic data. Principal component structure-oriented filters go one step further by using not only the five or nine samples along structural dip and azimuth, but also a suite of parallel slices above and below the target samples. For 11 slices, the statistics of such a filter is based on 55 or 99 samples. Such filters accurately preserve lateral changes in seismic amplitudes. All three of these filters – mean, median and principal component – can be applied in an edge-preserving manner and reject noise. For more details on these filtering methods, the readers may wish to refer to Causes and Appearance of Noise in Seismic Data Volumes, Search and Discovery Article #41476.

Dealing with Artifacts

Surprisingly, after the application of an edge-preserving structure-oriented filter, rather than improving the results of relative acoustic impedance, artifacts in the form of vertical striations appear on the resulting display. Relative acoustic impedance inversion does not require the interpreter to provide a source wavelet or a background model, with most implementations involving a trace-integration step.

In Figure 1a we show a segment of a section from the input seismic data volume and its edge-preserving median filtered version (Figure 1b). The latter looks cleaner than the input section, as expected. In Figure 2 the sections from the relative acoustic impedance volumes are shown equivalent to the sections shown in Figure 1. While the relative impedance section in Figure 2a looks reasonable and devoid of any artifact, the relative impedance attribute generated on median-filtered data and shown in Figure 2a exhibits pronounced vertical striations as artifacts.

On exploring the reasons for the occurrence of such an artifact and in our discussion with some fellow colleagues, it was concluded that additional low frequencies below that of the input data are being introduced. Examining the frequency spectra of the input seismic data as well as median-filtered data in a time window between 1 to 2 seconds, shown alongside the sections shown in Figure 1, we notice a small change in the low-frequency end of the spectrum after median filtering indicated by the blue ellipse. Applying a bandpass filter (4-12, 90-100 Hertz) to the median-filtered seismic data and then generating relative acoustic impedance, the vertical impedance artifacts disappear. Figure 3 shows the equivalent sections to those shown in Figure 1 and Figure 2.

We repeated the exercise on input seismic data put through principal component structure-oriented filtering and then generation of relative acoustic impedance. The results showed the artifact, except that it was less pronounced, as seen in Figure 4. Again, after application of a bandpass filter on the principal component structure-oriented filtered volume and generation of relative acoustic impedance volume, the artifact disappears (Figure 5).

Analysis

All edge-preserving structure-oriented filters are nonlinear, where the filter applied to a data window straddling a discontinuity is different than one that does not. Near the edges, the applied filters are changed to be one-sided rather than centered about the analysis point. Consider a suite of flat reflectors. If the discontinuity is vertical, the spectrum of the seismic wavelet is unchanged. However, if the discontinuity dips at 60 degrees, the filter attempts to sharpen the edge, in essence “breaking” the wavelet, such that the peak of the wavelet above the dipping fault undergoes a different filter than the trough below the dipping fault. Although such discontinuous events are appealing to an interpreter and enhance edge-sensitive attributes such as coherence, the “sharpened” edges include both high and low frequencies not recorded in the original seismic data. These low frequency artifacts give rise to the striping seen in trace-integration based relative acoustic impedance volumes.

Conclusions

Edge-preserving structure-oriented filters are nonlinear filters that can improve the interpretability, the performance of autotrackers, and the response of seismic attributes such as coherence. In addition to suppressing short wavelength noise, these filters can also introduce low- and high-frequency spectral components not measured in the original seismic acquisition program. We have identified a pitfall in using such data as input to relative acoustic impedance inversion. To address this pitfall, we recommend the interpreter apply a low-cut (0-4 Hertz) filter to the conditioned data prior to running relative impedance inversion.

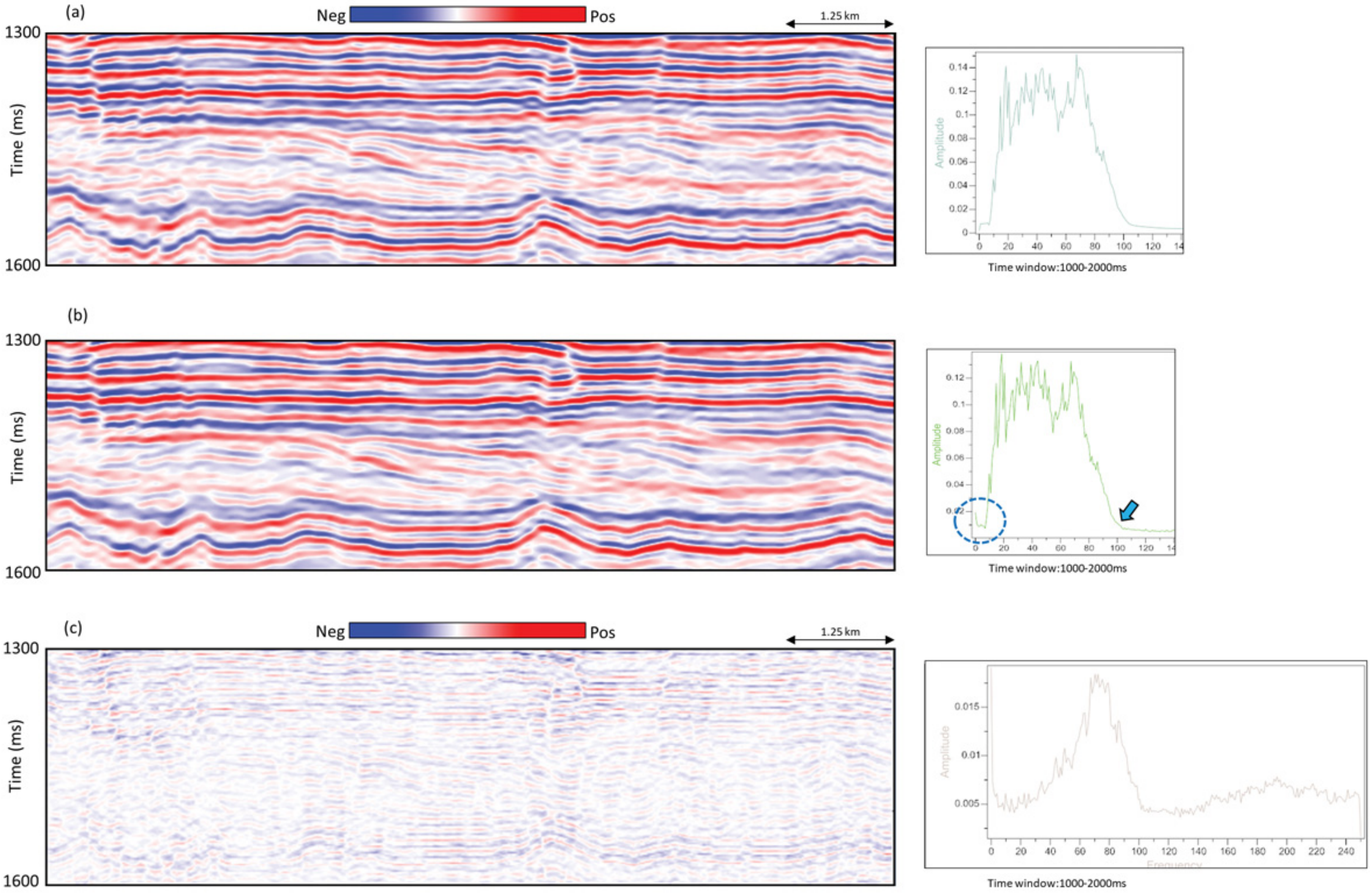

Figure 1. Segment of a section from (a) input seismic data volume, and (b) input seismic data volume after 3x3 median filtering. The section looks somewhat cleaner. The frequency spectra for the two data volumes were generated over a window from 1 to 2 seconds, which represents the broad zone of interest, though only 300 milliseconds of the data are shown in the two displays. (c) Image of the rejected “noise” obtained by subtracting (b) from (a). The noise level is down by a factor of 20 from the original amplitude data and consists mostly of short-wavelength artifacts that fall within the spectrum of the original seismic data. However, note that there is “noise” that has been added to the spectrum at both the high and low end of the spectrum. We associate these features with the edge preservation part of the filter. Data courtesy of TGS, Calgary.

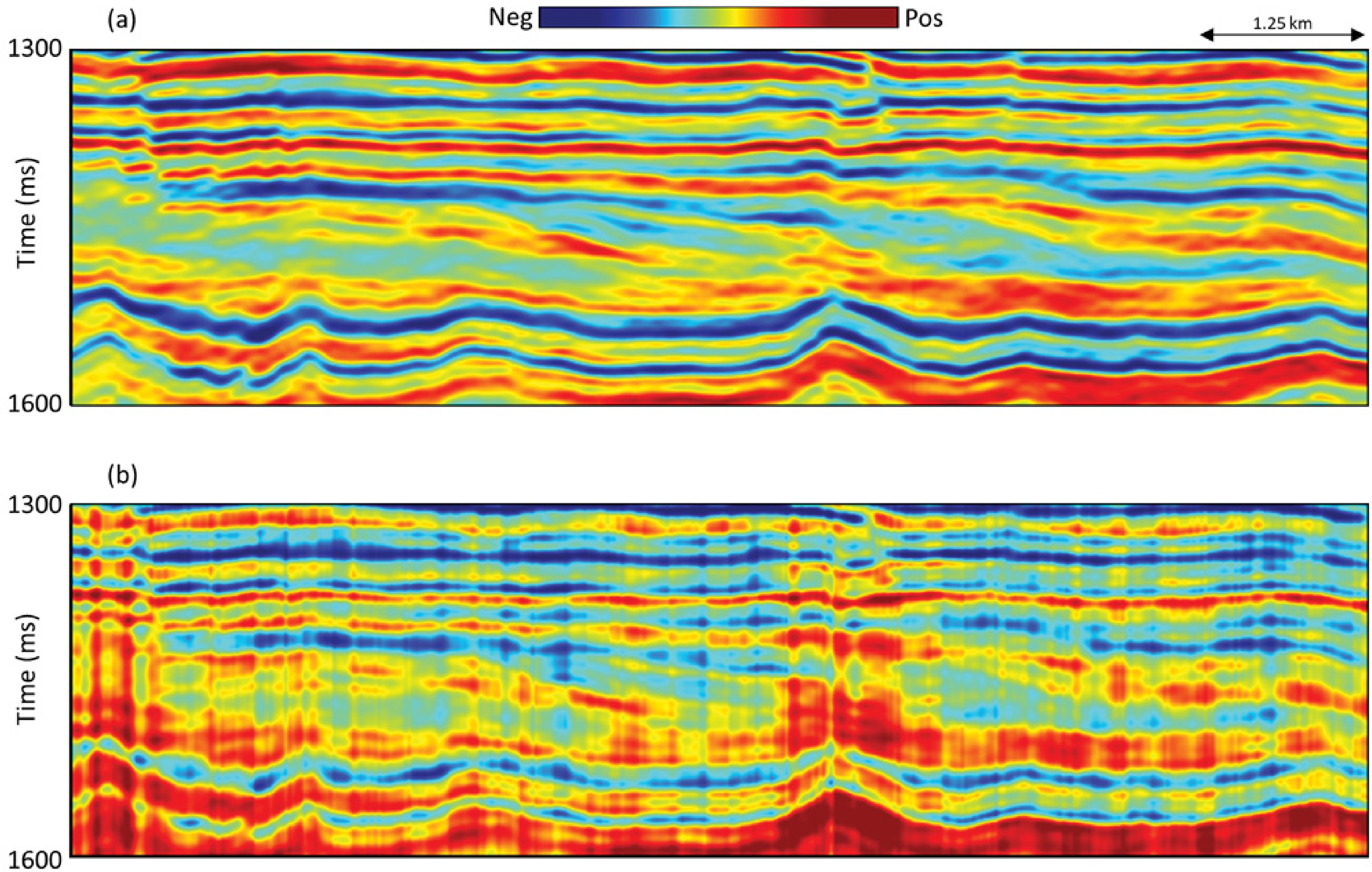

Figure 2. Equivalent sections from relative acoustic impedance generated on (a) input seismic data volume, and (b) input seismic data volume after 3x3 median filtering. While the relative impedance on input data shown in (a) looks reasonable, the same attribute run on the median-filtered data shows artifact in the form of vertical striations. Such artifacts are unacceptable.

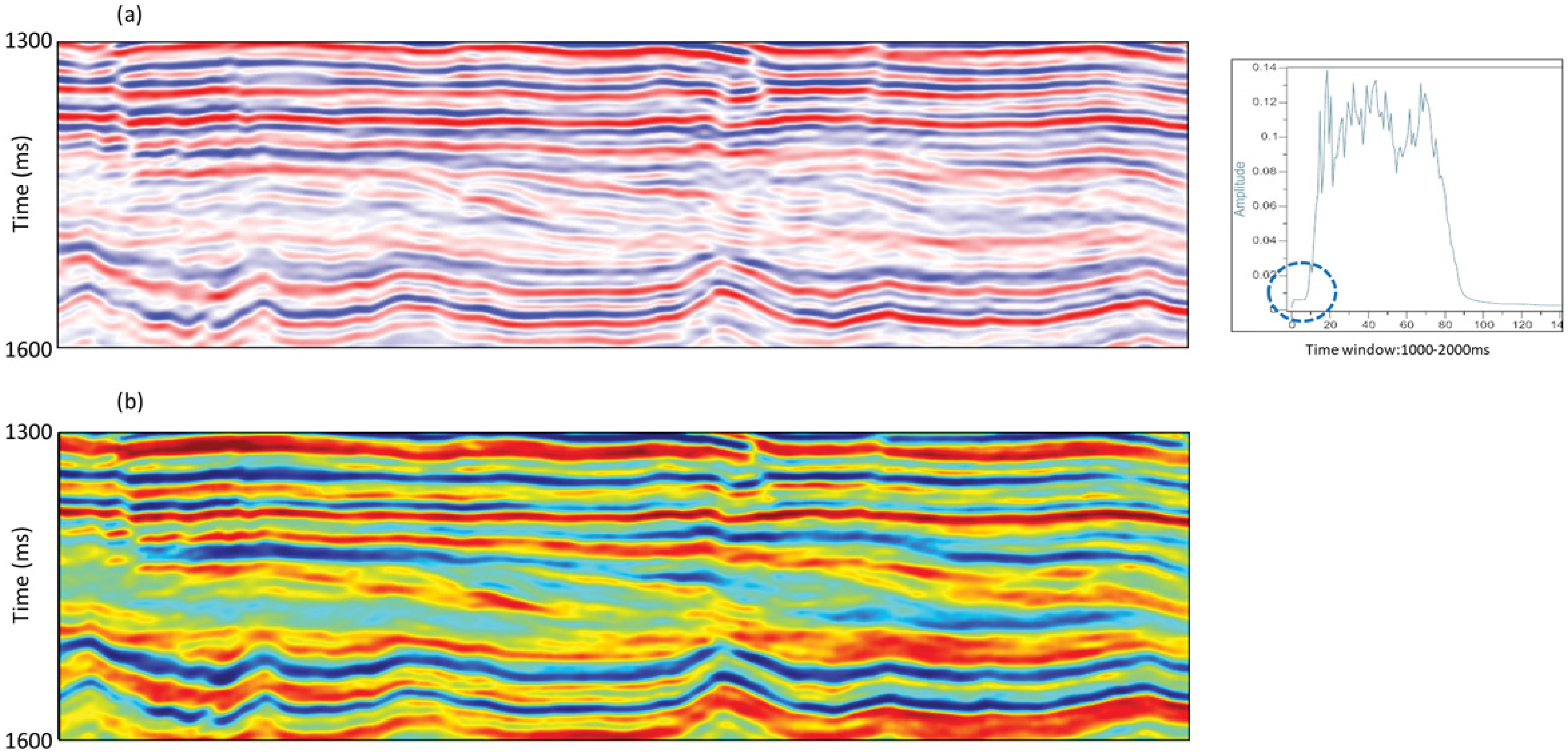

Figure 3. Equivalent sections from (a) input seismic data volume after 3x3 median filtering and bandpass filtering (4-12-90-100 Hertz), and (b) relative acoustic impedance on the data shown in (a). The impedance section looks reasonable.

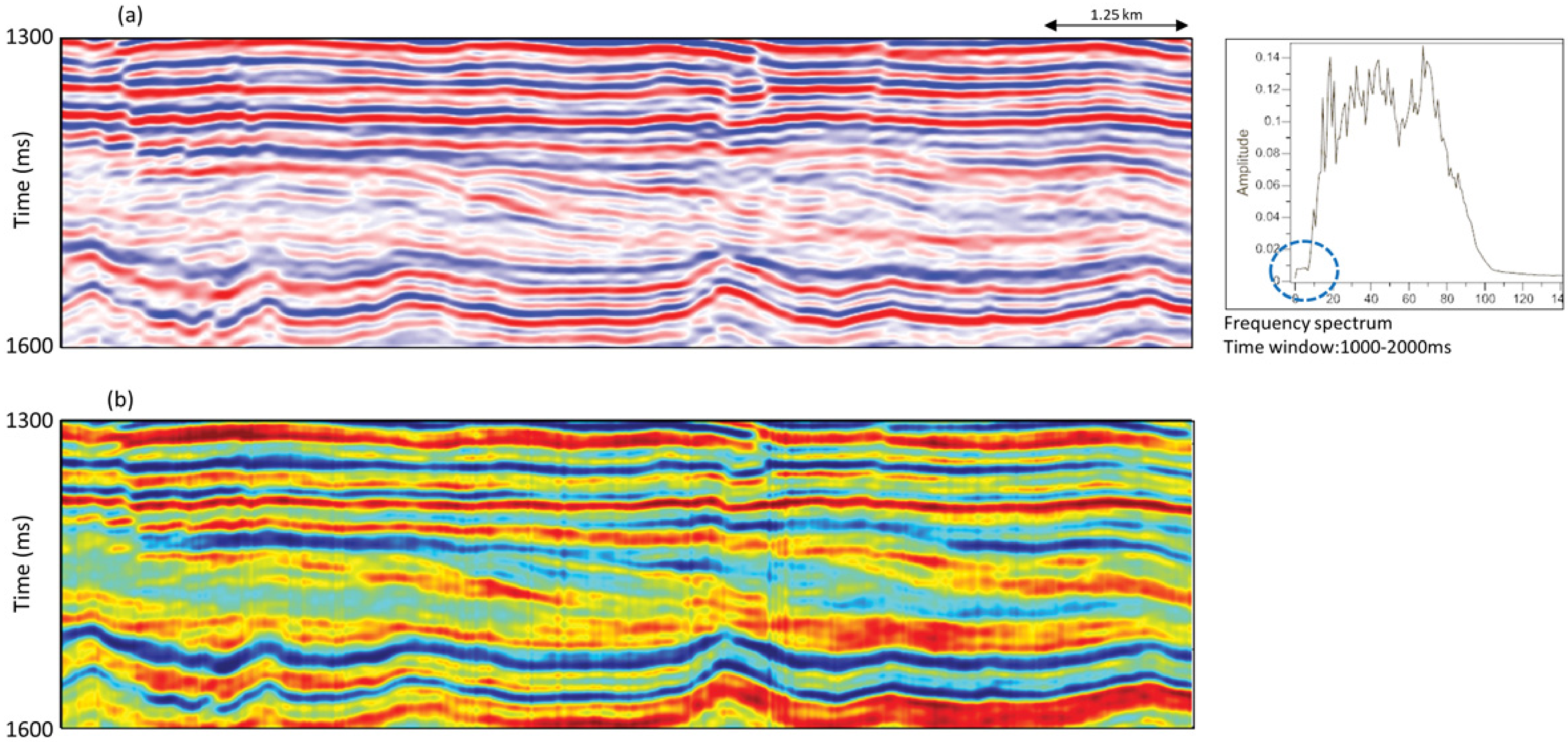

Figure 4. Equivalent sections from (a) input seismic data volume after principal component structure-oriented filtering, and (b) the relative acoustic impedance on the data shown in (a). Again, we notice the vertical striation artifact on the impedance section.

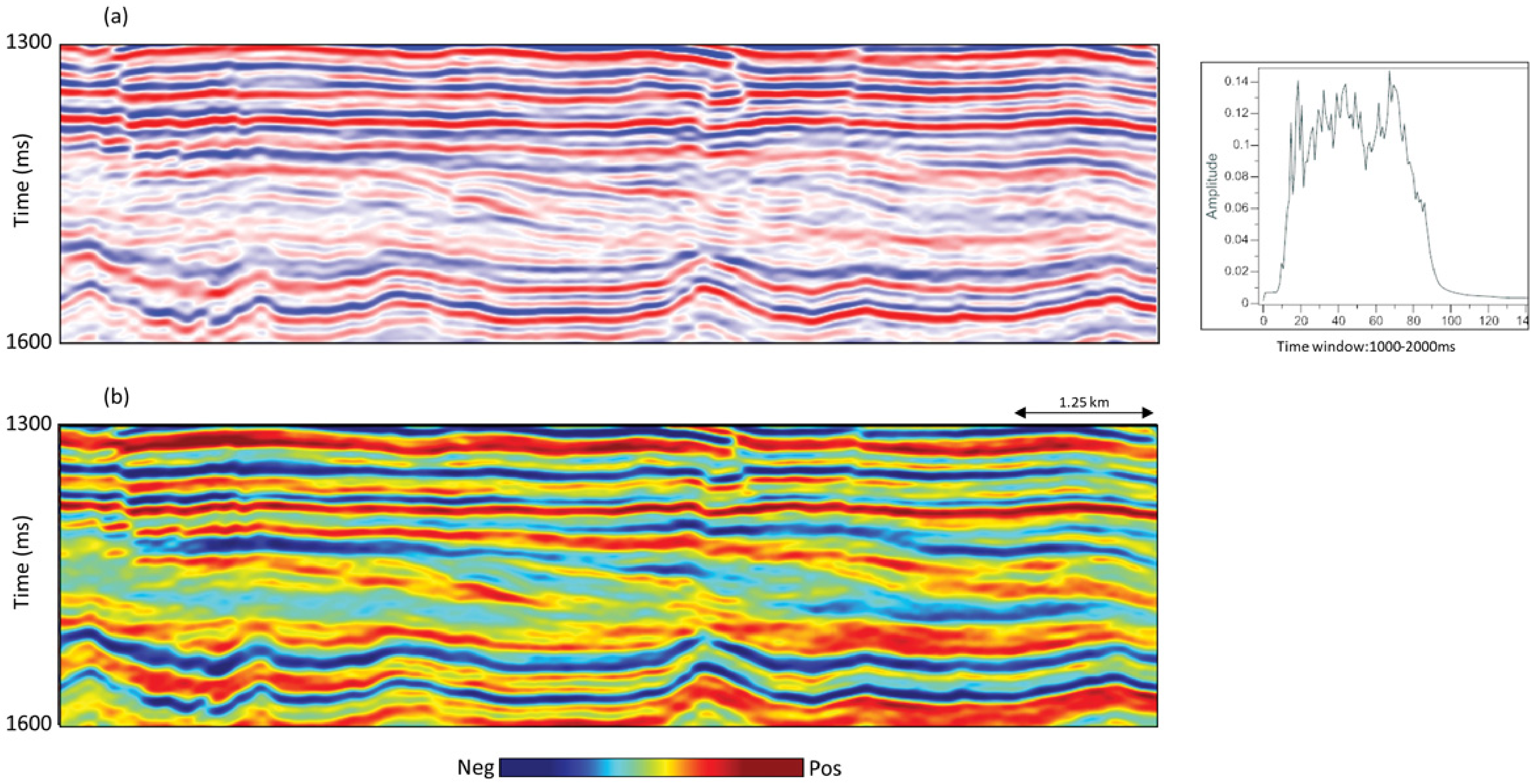

Figure 5. Equivalent sections from (a) input seismic data volume after PCA filtering and bandpass filtering (4-12-90-100 Hertz). (b) The relative acoustic impedance on the data shown in (a) looks reasonable.