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Seismic Attributes on Frequency-enhanced Seismic Data

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Summary

Seismic data are usually contaminated by both random and coherent noise, even when the data have been migrated reasonably well and are multiple-free. Seismic attributes are particularly effective at extracting subtle features from relatively noise-free data. Certain types of noise can be addressed by the interpreter through careful structure-oriented filtering or post migration footprint suppression. However, if the data are contaminated by multiples or are poorly focused and imaged due to inaccurate velocities, the data need to go back to the processing team to alleviate those problems.

Another common problem with seismic data is their relatively low bandwidth. Significant efforts are made during processing to enhance the frequency content of the data as much as possible to provide a spectral response that is consistent with the acquisition parameters. Ironically, the interpreters can be somewhat more aggressive in their filtering. The interpreters will have a better understanding of the geology, the play concept, access to any well data, and therefore be better able to keep or reject alternative filter products that are consistent or inconsistent with the interpretation hypothesis.

We begin our discussion by reviewing alternative means of suppressing random noise on our migrated seismic images, with the most promising methods being various implementations of structure-oriented filtering. Next, we address acquisition footprint, which may appear to be random in the temporal domain but is highly correlated to the acquisition geometry in the spatial domain.

After running the data through the cleaning phase, we evaluate alternative methods for frequency enhancement of the input seismic data. We illustrate the impact of these preconditioning steps on the computation of the attributes such as coherence and curvature on data volumes from Alberta, Canada. We conclude with a summary on the choice of the frequency-enhancement methods on the basis of the examples generated with different workflows.

Introduction– Alternative noise-suppression workflows

Suppression of random noise: Mean, alpha-trimmed mean, and median filters are commonly used during processing to suppress random noise. A more desirable application would be of a dip-steered mean or median filter, which has the effect of enhancing laterally continuous events by reducing randomly distributed noise without suppressing details in the reflection events consistent with the structure. The filter picks up samples 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. The median filter can also be applied iteratively, reducing random noise at each successive iteration, but will not significantly increase the high frequency geological component of the surface (Chopra and Marfurt, 2008).

Dip-steered mean filters work well on prestack data in which discontinuities appear as smooth diffractions, but smear faults and stratigraphic edges on migrated data. Dip-steered median and alpha-trimmed mean filters work somewhat better but will still smear faults. Hoecker and Fehmers (2002) address this problem through an “anisotropic diffusion” smoothing algorithm. The anisotropic part is so named because the smoothing takes place parallel to the reflector, while no smoothing takes place perpendicular to the reflector. The diffusion part of the name implies that the filter is applied iteratively, much as an interpreter would apply iterative smoothing to a time-structure map. Most important, no smoothing takes place if a discontinuity is detected, thereby preserving the appearance of major faults and stratigraphic edges. Luo et al. (2002) proposed a competing method that uses a multiwindow (Kuwahara) filter to address the same problem. Both approaches use a mean or median filter applied to data values that fall within a spatial analysis window with a thickness of one sample.

Marfurt (2006) describes a multiwindow (Kuwahara) principal component filter that uses a small volume of data samples to compute the waveform that best represents the seismic data in the spatial analysis window. Seismic processors may be more familiar with the principal component filter as equivalent to the Kohonen-Loeve (or simply KL) filter commonly used to model and remove multiples on NMO-corrected gathers using the multiple velocity. Examples of the application of structure oriented filtering on seismic data have been shown in Chopra and Marfurt, (2007, 2008), wherein improved event focusing and reduced background noise levels after structure-oriented filtering are clearly evident.

Suppression of acquisition footprint: Acquisition footprint is defined as any amplitude or phase anomaly closely correlated to the surface acquisition geometry rather than to the subsurface geology. Spatially periodic changes in total fold, azimuths, and offsets give rise to spatial periodicity in enhancement of seismic signal and rejection of seismic noise. Attributes exacerbate these periodic changes, giving rise to artifacts. Gulunay (2006) and others have shown that k_x-k_y filters can be very effective in reducing acquisition footprint on time slices for regularly sampled surveys. Since footprint due to fold, offset, and azimuth tends to be organized vertically, while that due to aliased migration artifacts is steeply dipping, k_x-k_y-ω or 3D running-window Radon filters may provide some additional artifact-suppression leverage. For more irregular acquisition design, the noise estimated using k_x-k_y or k_x-k_y-ω filters can be followed by an adaptive filter.

Enhancing the frequency bandwidth of seismic data

There are a number of methods that are used during processing to enhance the frequency content of the input seismic data. Here we mention a few commonly used processes followed by some relatively newer ones that help the interpreter to extract meaningful information from the seismic data.

Deconvolution: Different conventional procedures are adopted to compensate for frequency attenuation. A common practice has been to use a two- or three-window statistical deconvolution to correct for the dynamic loss of high frequencies. This involves choosing two or three time-windows for the deconvolution, each with its own parameters, keeping the time-variant nature of the embedded source wavelet in mind. These windows are usually made to overlap to avoid artifacts. However, there are problems with this approach: the filters must be derived from smaller windows, which are less likely to meet the statistical assumptions, and these windowed zones often exhibit phase distortions at the point of overlap.

Time-variant spectral whitening: The other method is to use time-variant spectral whitening (TVSW). The method involves passing the input data through a number of narrow band-pass filters and determining the decay rates for each frequency band. The inverse of these decay functions for each frequency band is applied and the results are summed. In this way, the amplitude spectrum for the output data is whitened in a time-variant way. The number of filter bands, the width of each band and the overall bandwidth of application are the different parameters that are used and adjusted for an optimized result (Yilmaz 2001). In this method, the high-frequency noise is usually amplified and so a band-pass filter must be applied to the resulting data. Since it is a trace-by-trace process, TVSW is not appropriate for AVO applications.

Inverse Q-filtering: If we had an analytic form for an attenuation function, it would then be easy to compensate for its effects. Thus, in practice, attempts are first made to estimate a *Q*-model for the subsurface. Inverse *Q*-filtering is then carried out, removing the time-variant wavelet effects by absorption and broadening the effective seismic bandwidth by correcting the loss of high-frequency signal. These attempts have met with a varying degree of success, depending on the assumptions used in the particular approach and how well they are met in practice.

Frequency split structurally oriented filtering: Helmore (2009) introduced frequency split structurally oriented filtering (Figure 1) wherein the input seismic data is divided into a number of frequency bands, followed by running structurally oriented filters separately to each of the bands and then recombining the results. This procedure reduces noise in selected frequency bands and results in higher signal-to-noise ratio as well as enhanced resolution. Structurally oriented filters do not suffer from windowing artifacts and are precisely adapted to the local dip (Helmore, 2009).

Spectral decomposition-based inversion for seismic reflectivity: Thin-bed spectral inversion (Chopra et al., 2006) is a process that removes the time-variant wavelet from the seismic data and extracts the reflectivity to image thicknesses far below seismic resolution using a matching-pursuit variant of sparse spike inversion. In addition to enhanced images of thin reservoirs, these frequency-enhanced inverse images have proven very useful in mapping subtle onlaps and offlaps, thereby facilitating the mapping of parasequences and the direction of sediment transport.

Figure 2a compares a segment of a 5–80 Hz seismic section from Alberta and its thin-bed reflectivity inversion (Figure 2b). Notice the increased detail in terms of extra cycles. It is convenient for an interpreter to convolve the derived reflectivity volume with a 5-120 Hz bandpass wavelet that would yield a high frequency volume. In addition to facilitating detailed interpretation, these ‘filtered’ volumes can serve as input for generating high-bandwidth attribute volumes.

In Figure 3 we show the amplitude spectra for the same data volume subjected to the different methods discussed above. Notice that the high-frequency volume generated from thin-bed reflectivity inversion serves to show the highest frequency enhancement. Depending on the quality of the data as well as the access to one of the methods discussed above, the data needs to be frequency-enhanced before the attributes can be computed effectively.

Attribute computation on preconditioned data

In Figure 4 we show stratal slices through attributes computed from both the original and higher-frequency data. Note that the improved frequency resolution does not significantly change the long-wavelength curvature. In contrast, the impact on coherence is significant, where we note increased lateral resolution of the channel system.

Conclusions

The motivation behind making this presentation is to emphasize the fact that computation of attributes is definitely not just a process that involves pressing some buttons on a workstation, but requires careful examination of the input seismic data in terms of frequency content as well as signal-to-noise ratio or any other noise contaminating the data.

We have compared the results of different frequency enhancement techniques like Q-compensation, spectral whitening, frequency-split structure-oriented filtering and thin-bed reflectivity inversion. We find that the enhancement in the frequency content for the data volumes analyzed, is in the order they have been stated above. Needless to mention, all these methods may not be available to an interpreter. However, this exercise serves to bring out the information that should be borne in mind while making choices for methods of frequency enhancement.

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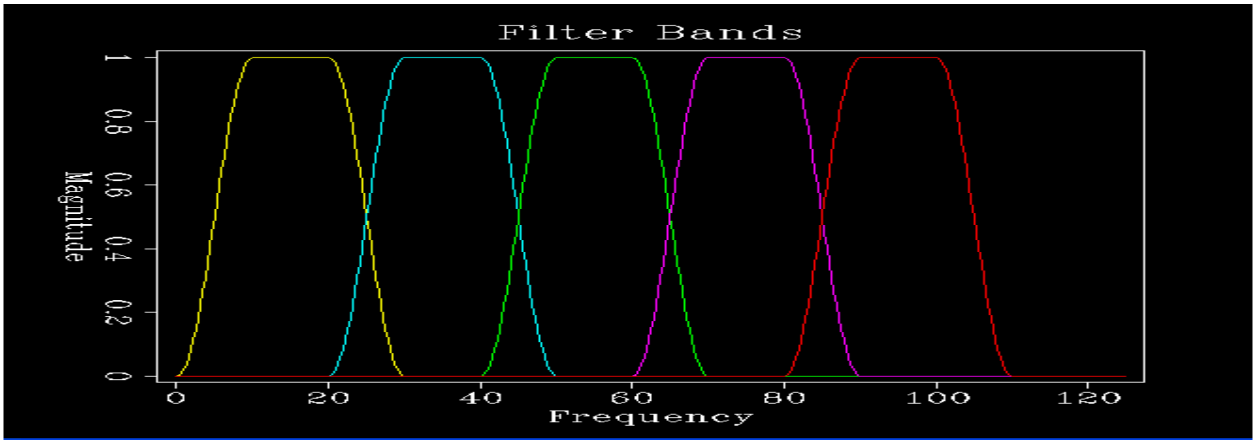


Figure 1: In frequency-split structure-oriented filtering, the seismic data are band-pass filtered and pc-filtered along the dip for each of the pass bands. The results are normalized to the amplitude of the original spectrum and then added. The figure shows five overlapping bands to which the data is subjected.

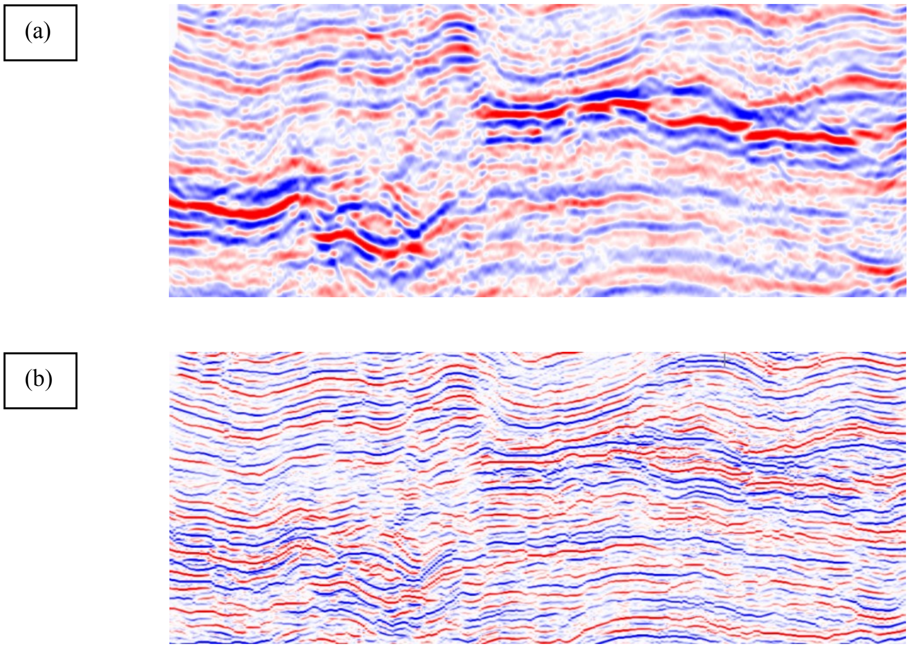


Figure 2: (a) A segment of a seismic section; (b) equivalent thin-bed reflectivity section derived from the input section. Notice the higher resolution as well the extra cycles that help the interpreter make more accurate interpretation.

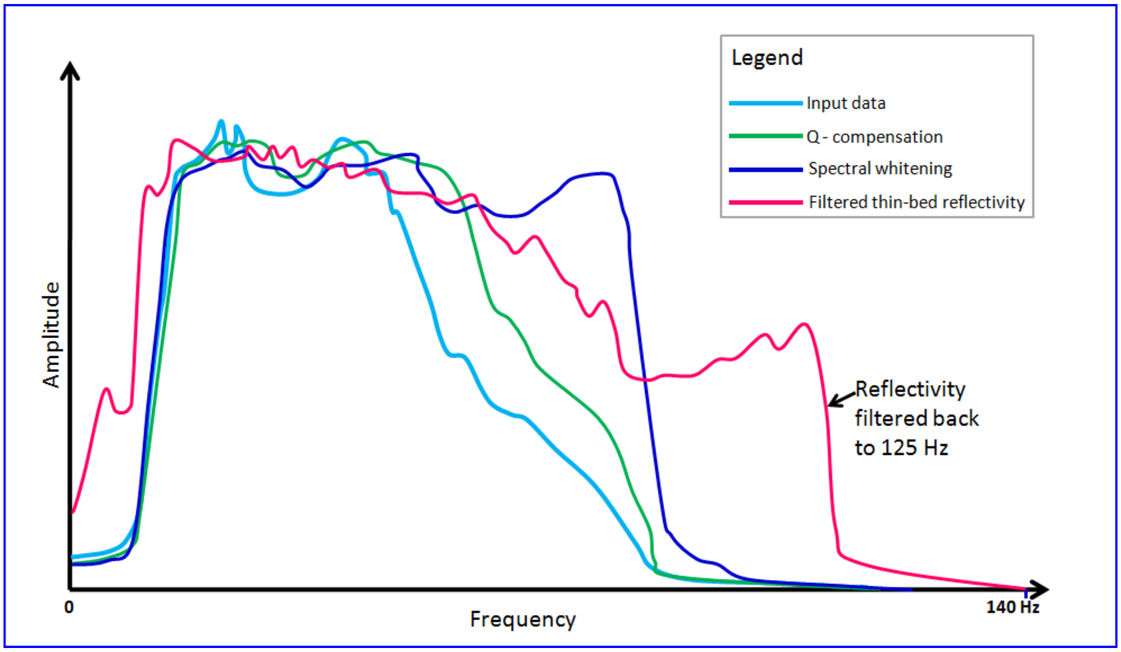
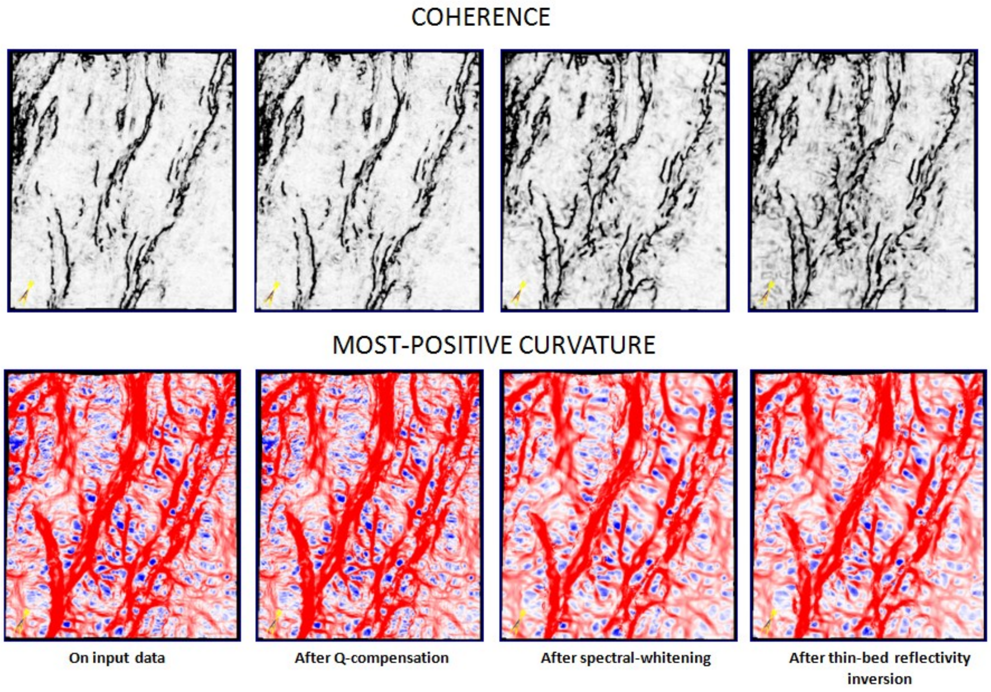


Figure 3: Amplitude spectra of frequency-enhanced different datasets using Q-compensation, spectral whitening and filtered thin-bed reflectivity. While Q-compensation as expected shows a marginal increase in frequency content, spectral whitening shows much more increase and the filtered thin-bed reflectivity (high-end cut off at 125 Hz) shows the maximum increase in frequency content.



On input data

After Q-compensation

After spectral-whitening

After thin-bed reflectivity inversion

Figure 4: Stratal slices from the coherence (above) and most-positive curvature (long-wavelength) (below) attributes run on the input as well as other frequency-enhanced seismic data as indicated. Note that the coherence shows much more detail on the filtered thin-bed reflectivity version than the others. The most-positive curvature shown here is the long wavelength version and shows only somewhat more detail. However, the short-wavelength version exhibits more detail as will be shown in the presentation.