[GC] Resolving Thin Beds and Geologic Features by Spectral Inversion*

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General Statement

Expanding the frequency bandwidth of surface seismic data is an unending quest for geophysicists because increased seismic resolution is essential for extracting stratigraphic detail from seismic images. While both vertical resolution and horizontal resolution are important for interpreting small geologic features on seismic data, we focus our attention here on vertical resolution – recognizing that migration procedures usually enhance horizontal resolution.

If the frequency spectrum of a seismic wavelet is centered around 30 Hz, which is usually achievable, and the seismic interval velocity is greater than 3000 m/s, reservoirs having a thickness less than 25 meters may not be resolved. "Not resolved" means there is no distinct reflection peak or trough centered on the top and bottom interfaces of the reservoir unit.

This interval thickness, where seismic data can no longer position a distinct reflection peak or trough at the top and base of the interval, is called "tuning thickness." Because numerous stratigraphic targets have thicknesses of 10 meters or less – which is thinner than tuning thickness for most seismic profiles – frequency enhancement procedures need to be applied to seismic data to study reservoir targets in this "thinner than tuning thickness" domain.

Method

One post-stack spectral inversion method that resolves thin layers having a thickness less than tuning thickness was described by Portniaguine and Castagna (2005) and then by Chopra et al. (2006). This method is driven by geological principles rather than by mathematical assumptions and uses spectral decomposition to enhance the frequency spectrum local to a thin-bed unit.

This spectral, or thin-bed reflectivity, inversion outputs a reflectivity series, and the apparent resolution of the inversion product is superior to the resolution of the input seismic data used to generate the reflectivity response. Applications of this method in deconvolving complex seismic interference patterns are changing the mindset of many seismic interpreters because the technique shows stratigraphic patterns with such remarkable detail.

The method consists of the following steps:

1. A set of time-varying and space-varying wavelets is estimated from the seismic data. For this purpose, it is good to have well control data to aid in selecting optimal space and time dependencies that should be expressed by these wavelets. In the absence of well control, a statistical method of wavelet estimation can be adopted.

2. The wavelets estimated in step 1 are removed from the seismic data using an inversion procedure in which spectral constraints are derived on the basis of spectral decomposition procedures. It is important to note that no Earth model or any assumption about stratigraphic layering is used in this inversion procedure – the trace-by-trace inversion procedure requires no starting geologic model and has no lateral continuity constraints.

Thin-bed Reflectivity Example

Figure 1 shows a comparison of a segment of a seismic section from Alberta, Canada, before and after reflectivity inversion. After reflectivity inversion, more reflection detail can be seen, and faults are shown with improved clarity.

Once thin-bed reflectivity is derived from an input seismic volume – using, for example, a wavelet derived from an existing well – an interpreter can determine the amount of uncertainty involved in the inversion process by using a blind-well test. Our experience with such exercises suggests that thin-bed spectral inversion creates data that tie favorably with other wells positioned in the same 3-D seismic volume.

Figure 2 shows a comparison between a segment of an input seismic section (Figure 2a) and an equivalent segment of thin-bed reflectivity that has been convolved with a bandpass wavelet that extends the high end of the frequency spectrum to 120 Hz (Figure 2b). Enhanced resolution of the reflectivity section is indicated by the extra reflection cycles. More individual reflection cycles can now be tracked, leading to more detailed interpretation of the data.

Attribute Extraction Example

Seismic attributes are a great help in extracting geologic information and are widely used to map geologic features at many scales. Geologic information not revealed by conventional displays of seismic data can often be seen on displays of one or more attributes derived from the data. As a result, there has been an explosive growth in the development and application of seismic attributes. Attribute computation done on data with enhanced resolution proves to be particularly useful for mapping onlap and offlap patterns or other stratigraphic features, which facilitates the mapping of parasequences and the direction of sediment transport.

Figure 3 shows a comparison of a stratal slice through a coherence-attribute volume generated for both input seismic data and for enhanced-resolution data. Notice the significant impact that enhanced resolution has on the coherence attribute, as evidenced by the increased lateral resolution of the channel system and by the improved faulting picture seen in Figure 3b.

Conclusion

The thin-bed spectral inversion method discussed here is a novel way of removing wavelet effects from seismic data to create a pure reflectivity sequence. For data with a high signal-to-noise ratio, units with thicknesses less than the tuning thickness of the input data can be resolved.

The improved-resolution seismic data retrieved in the form of reflectivity data are not only important for more accurate geologic interpretations but prove to be advantageous for:

1) Convolving the extracted reflectivity with a wider bandpass wavelet (say 5-120 Hz) to provide a high-frequency section.

2) Providing high-frequency attributes that enhance lateral resolution of geologic features.

References

Chopra, Satinder, John P. Castagna, O. Portniaguine, 2006, Seismic resolution and thin-bed reflectivity inversion: CSEG Recorder, v. 31, no. 1, p. 19-25.

Portniaguine, O. and John P. Castagna, 2005, Spectral inversion - lessons from modeling and Boonesville case study: 75th SEG Meeting, p. 1638-1641.

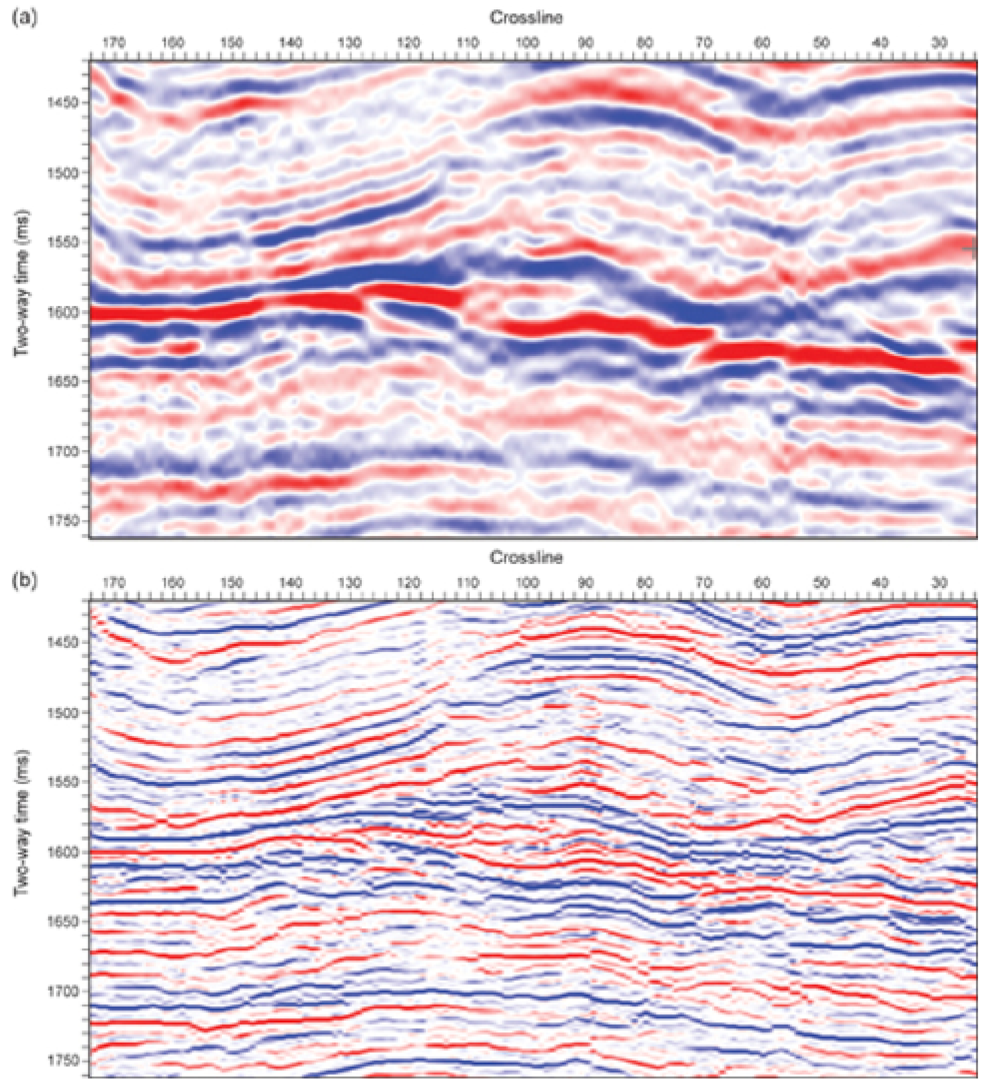

Figure 1. Comparison of (a) a conventional seismic section and (b) its derived thin-bed reflectivity. More geologic detail can be seen with the reflectivity data than with the input data.

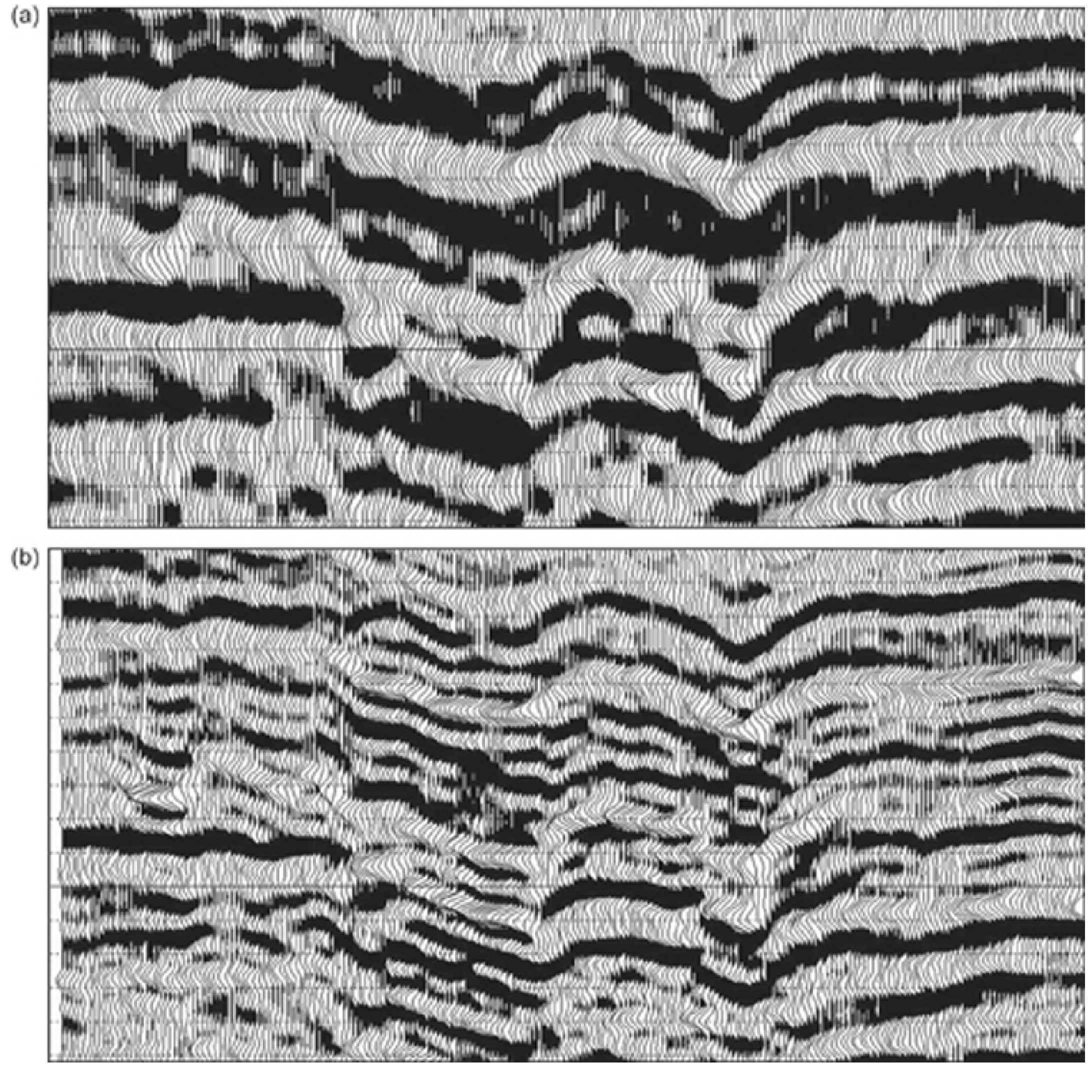

Figure 2. Comparison of (a) a segment of a band-limited seismic section and (b) the equivalent section derived when thin-bed reflectivity is convolved with a 5- to 120-Hz bandpass wavelet. The section in panel b has enhanced resolution.

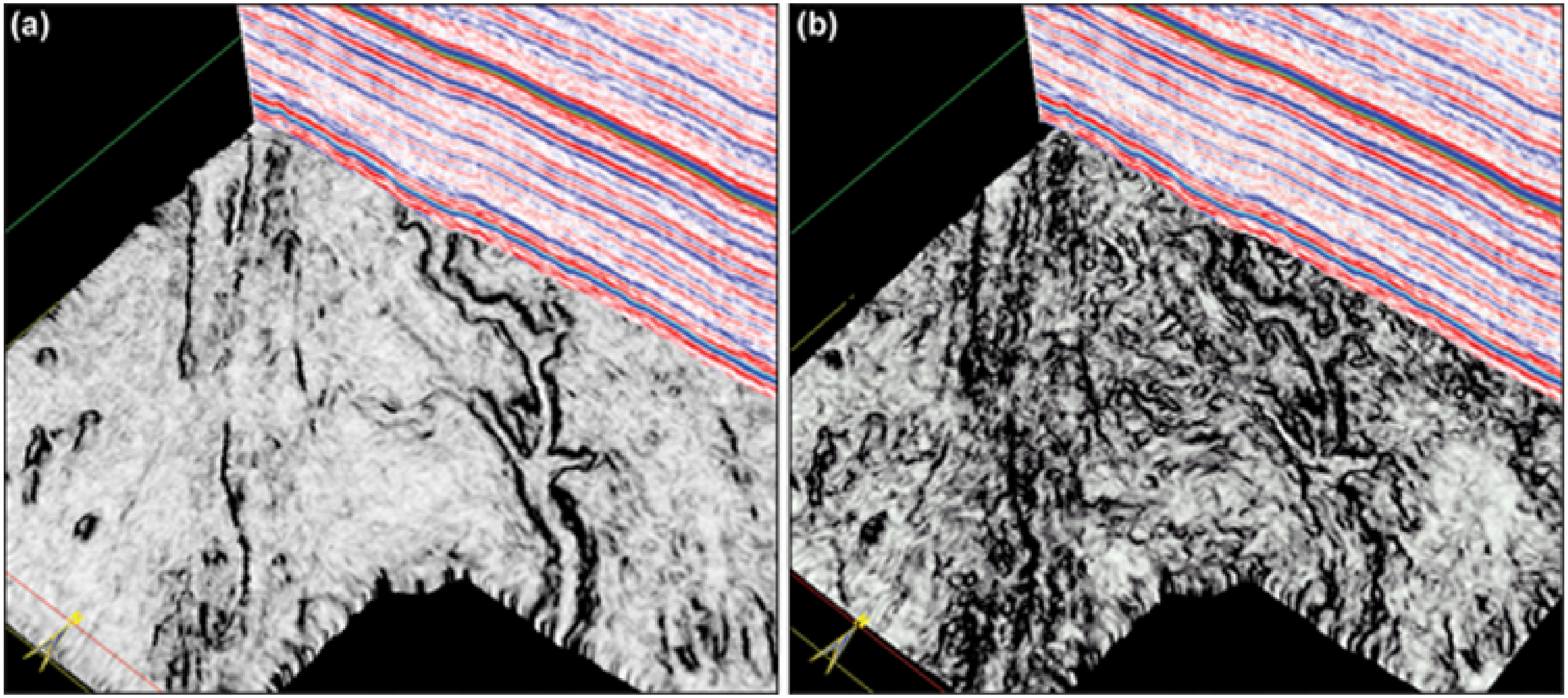

Figure 3. Stratal slices from (a) a coherence-attribute volume derived from band-limited seismic data and (b) thin-bed reflectivity convolved with a 5- to 120-Hz band pass wavelet. Features can be seen with better definition and clarity on such attribute slices.