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High-Resolution Geological Visualization Using Spectral Inversion

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Abstract

Conventional seismic inversion operates in the time domain and outputs relative impedances. Spectral inversion (Portniaguine and Castagna, 2005; Partyka, 2005) operates in the frequency domain where the spectrum of a local seismic response is taken to be a superposition of sinusoidal transfer functions associated with reflection coefficient pairs. Thus, the output time domain reflectivity series is a superposition of odd and even impulse functions. Widess (1957; reprinted in 1973) showed that odd impulse functions have a resolution limit of about $1/8^{\text{th}}$ of a wavelength, below which the response is approximately the derivative of the seismic wavelet, irrespective of layer thickness. As an odd impulse pair thins below this limit, the peak frequency of the response remains relatively constant while the amplitude decreases almost linearly with thickness. According to this model, for layer thickness below $1/8^{\text{th}}$ of a wavelength one cannot separate differences in reflection coefficient magnitude from changes in layer thickness (even in the absence of noise), and thus $1/8^{\text{th}}$ of a wavelength is generally considered the limit of seismic resolution. However, for even impulse pairs, response frequency varies continuously with layer thickness and, in the absence of noise, layer thickness and reflection coefficient magnitude can both be precisely determined. Thus, for an isolated layer with an even component of reflectivity, resolution is nearly perfect in the absence of noise. Spectral inversion, by appropriately weighting odd and even components of reflection coefficient pairs, can thus achieve the best possible combination of resolution and robustness to noise. As is the case with all sparse-spike inversion methods, the output reflectivity series contains frequency components outside the band of the original

seismic data. As the spectra of impulse pairs are sinusoids with infinite frequency content, in the absence of noise, all frequencies out to Nyquist can theoretically be recovered. In practice, in the presence of noise, the useful data bandwidth can often be increased by a factor of two or three. The broader the bandwidth of the original data, the more robust the process is against noise. By examining filter panels of the output reflectivity series, one can select the bandwidth that provides the most enhanced "spectrally broadened" image. Filtering back to the original bandwidth of the data reproduces the original data – the process is thus amplitude preserving and does not introduce "false" events. The spectral inversion method applied here requires no "starting model" and consequently makes no direct use of well information. The results are thus objective in the sense that they have not been biased by any interpretive input.

Examples

Case studies from Lake Maracaibo and the deep-water Gulf of Mexico illustrate the image improvement that results from such a process. It is important to note that in these case studies the only use of well control was in wavelet extraction and verification of results. No well information was incorporated into the inversion process.

Figure 1 compares a conventional seismic section from Lake Maracaibo to a section spectrally broadened using spectral inversion. The increased frequency content (and corresponding improved resolution) after spectral broadening is obvious. Notice also, that the spectrally broadened data, though higher frequency, maintains the signal-to-noise ratio of the input data – something that cannot be done with inverse filtering methods such as deconvolution. Improvements in the geological picture provided by the spectral broadening include (1) discernable sub-tuning layer thickness changes as shown in Figure 2, (2) greatly improved fault definition (3) better imaging of events that were suppressed by destructive interference as shown in Figure 3, (4) generally improved interpretability as shown in Figure 4, and (5) previously undetectable stratigraphic patterns. Comparison of spectrally broadened to original seismic data reveals that the seismic wavelet produces interference patterns that are far more destructive to the geological picture than is generally appreciated by