Assumptions and pitfalls in interpreting the spectral response of stratigraphic layering

Kurt J Marfurt

The University of Oklahoma

ABSTRACT

Introduced to interpreters in the mid-1990s, spectral decomposition is routinely used to identify and delineate stratigraphic features on large 3D seismic surveys. The most common workflow is to select three spectral magnitude components near the tuning frequency of a target feature and display them against red, green, and blue. Interpreters then couple their understanding of the tuning model to visualize lateral changes in thickness with concepts of seismic geomorphology to map architectural elements of depositional features of interest. Modern software tools not only allow easy cycling through multiple spectral components to enhance a specific feature, but also the extraction of 3D geobodies.

While RGB color blending provides a more detailed rendering of the complete spectrum, the peak frequency (the mode of the spectrum) is more directly related to the tuning thickness. There are several pitfalls in correlating spectral components to temporal thickness. The most common pitfall is to not account for the spectrum of the source wavelet. This pitfall can be ameliorated by spectrally balancing the amplitude before or during the computation of the spectral components. A second pitfall is to not recognize that there may be more than one tuning frequency in your data, especially for thicker layers, where the first tuning frequency may fall below the lower frequency limit of your seismic data. Such thicker layers are usually well resolved, so that a simple QC against the peak-to-peak or peak-to-trough thickness will identify the pitfall. Furthermore, the location of the tuning peaks occur at different frequencies, f, for a layer of temporal two-way thickness T for reflectors of opposite sign at $f=(n+\frac{1}{2})/T$ and of the same sign at $f=n/T$. Ideally, if one can measure both peaks and notches in the spectrum this ambiguity goes away while at the same time defining the relative sign of the top and bottom reflector. Less important is the change in tuning frequency with incident angle by $1/\cos\vartheta$, increasing by 15% at 30°. Stacking reflection events ranging from 0° to 30° therefore will only slightly increase the tuning frequency above that of the normal incidence model.

Some patterns give rise to a smooth spectrum. For a simple interface (no thin bed) the spectrum varies as f^0 (i.e., it doesn't change from that of the balanced wavelet). For very thin beds the first tuning frequency may extend beyond the upper range of the measured spectrum. In this case, the spectrum increases as f^{+1} and exhibits a ±90° phase shift for top and bottom reflectors of opposite polarity, For reflectors of the same polarity these very thin beds exhibit a spectrum that varies as $1-f^{-2}$. If the impedance increases or decreases linearly with depth the spectrum varies as f^{-1} and undergoes a ±90° phase shift. These latter limiting cases suggest measuring the log-normal slope of the spectrum. If the slope is not smooth, we expect tuning.

Because the objective of seismic processing is to produce as flat a spectrum as possible, and because we need to further balance the spectrum prior to spectral decomposition, the final spectrum is rarely Gaussian. For this reason, estimates of instantaneous bandwidth are inaccurate; furthermore, many commercial software packages have implemented instantaneous bandwidth using an error that crept in

the 1970s. If this is the case, avoid using such calculations and if possible, compute the bandwidth explicitly using spectral decomposition.

Finally, there are several bandwidth extension techniques available in the marketplace. The one based on the continuous wavelet transform ridges (of which I am a codeveloper of one implementation) gives cosmetic improvements for areas that are already resolved and gives high resolution (but erroneous) results for areas that are not resolved. In contrast, the technique based on computing the coefficients of a library of opposite and of equal wavelet doublets uses the resolved high frequency spectral components to constrain a model that also fits the unresolved low frequency spectral components provides accurate results. However, this technique requires an accurate estimate of the source wavelet. The inverted model can then be convolved with a broader band wavelet to produce a reflectivity sequence consistent with the measured data, but (obviously) lacks any reflectivity not measured by the original seismic experiment.

I will illustrate these concepts with a few theoretical curves and spectra, a few synthetics, some real data examples, and then open the topic for discussion.

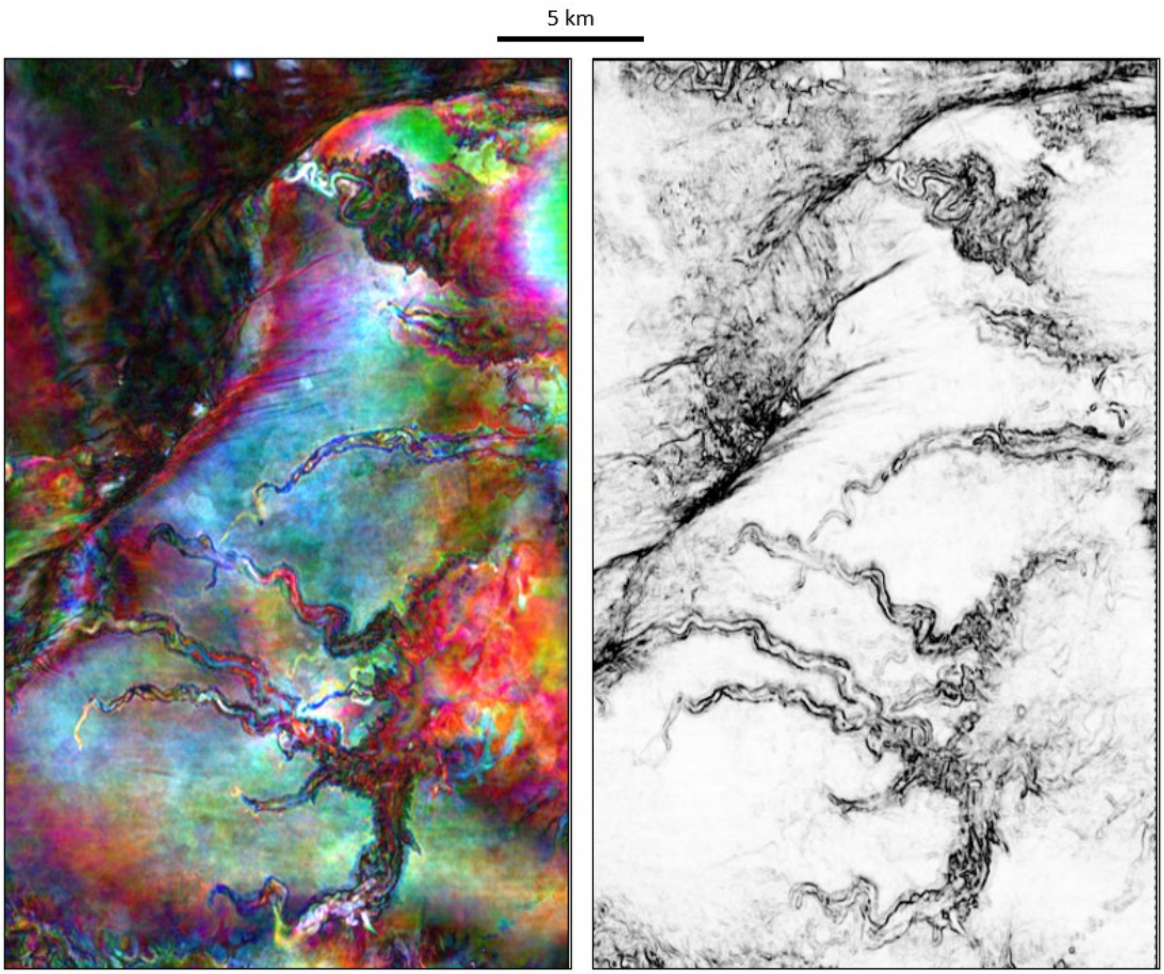

Figure 1. Time slices at t=1.320 s through the (Left) corendered spectral magnitude components at 30, 40, and 50 Hz plotted against red, green, and blue and (Right) the corresponding multispectral coherence image. The two attributes provide complementary images of the channel systems.

Bio:

Kurt Marfurt is an Emeritus Professor of Geophysics at the University of Oklahoma, where he mentors students and conducts research to aid seismic interpretation. Marfurt's experience includes 23 years as an academician, first at Columbia University, then later at the University of Houston and the University of Oklahoma. His career also includes 18 years in technology development at Amoco's Tulsa Research Center working on a wide range of topics At OU, Marfurt led the Attribute-Assisted Seismic Processing and Interpretation (AASPI) consortium with the goal of developing and calibrating new seismic attributes to aid in seismic processing, seismic interpretation, and data integration using both interactive and machine learning tools. He has served as Editor-in-Chief for the AAPG/SEG journal Intepretation, as a distinguished short course instructor for the SEG/EAGE in 2006, and for the SEG in 2018 and as an SEG Director-at-Large for 2019-2022.