GCSpectral Decomposition’s Analytical Value*

Satinder Chopra[1] and Kurt J. Marfurt[2]

Search and Discovery Article #41260 (2013)
Posted December 23, 2013

*Adapted from the Geophysical Corner column, prepared by the authors, in AAPG Explorer, December. Editor of Geophysical Corner is Satinder Chopra (schopra@arcis.com). Managing Editor of AAPG Explorer is Vern Stefanic.

[1] Arcis Corp., Calgary, Canada (schopra@arcis.com)
[2] University of Oklahoma, Norman, Oklahoma

General Statement

Stratigraphers use seismic data in two major ways:

- Defining boundaries associated with sea level and topography between important depositional packages or sequences.

- Mapping individual components or “architectural elements” of a given depositional system.

Using modern and paleo analogs as well as well control, the interpreter uses such boundaries and features to map seismic facies, which in turn can be related to lithology. The interpretation of discrete stratigraphic features is limited by both the bandwidth and the signal-to-noise ratio of the seismic data.

Unfortunately, well-resolved reflections from the top and base of subtle stratigraphic geologic boundaries occur only for thick features imaged by broadband data. Seismically thin stratigraphic features approaching a quarter wavelength thickness give rise to composite, or “tuned,” seismic reflections. Direct estimation of stratigraphic thickness is more difficult, with the definition of many of the features of interest, such as channel systems, becoming more muted.

Fortunately, the tuning phenomena also can help delineate such unresolved features – specifically, the composite amplitude of a thin layer is strongest (and usually has the highest signal-to-noise ratio) at the quarter wavelength tuning frequency. Thus, if we “probe” the subsurface with the correct frequency, we can better delineate our target.

We have shown how channel features are seen clearly on a 40 Hz spectral display. The coherence attribute run on spectral data yields much better definition of the channel features. We will illustrate the use of spectral decomposition for obtaining clearer definition of the subtle fault features in a future article.

Methods

A previous Geophysical Corner article (Search and Discovery Article # 40454) showed how low frequency components (specifically that part of the data < 16 Hz) had a higher signal-to-noise ratio. Over the last decade or so, spectral decomposition has become a well-established tool that helps in the analysis of subtle stratigraphic plays and fractured reservoirs.

As the name suggests, spectral decomposition decomposes the seismic data into individual frequency components that fall within the measured seismic bandwidth, so that the same subsurface geology can be seen at different frequencies. Thick beds or features will be tuned and have relatively higher amplitude at lower frequencies, while thin beds will be tuned and have relatively higher amplitude at higher frequencies.

Spectral magnitude highlights features that are tuned, and spectral phase components enhance subtle fault and channel edges that can be used as input to subsequent seismic attribute analysis, such as coherence. Spectral decomposition is done by transforming the seismic data from the time domain into the frequency domain; this can be done simply by using the discrete Fourier transform.

There are other methods that also could be used for the purpose, such as:

- The continuous wavelet transform.
- The S-transform.
- The matching pursuit decomposition.

Each of these methods has its own applicability and limitations, and the choice of a particular method also could depend on the end objective. For example:

- The discrete Fourier transform uses a time window for its computation, and this choice has a bearing on the resolution of the output data.
- The continuous wavelet transform depends on the choice of the mother wavelet, and usually yields higher spectral resolution but reduced temporal resolution.
- The S-transform method can be regarded as an extension of the continuous wavelet transform method when a Morlet wavelet is used as the mother wavelet, where the temporal window size is inversely proportional to the frequency being analyzed.

The S-transform method is better than the continuous wavelet transform method, as it yields good temporal and spectral resolution. The matching pursuit method does not need any windowing and so yields both good temporal and spectral resolution. It is, however, computationally more expensive.

There are a number of commercial or proprietary implementations of spectral decomposition that are routinely used in the industry and are based on some variation of the above methods. Using any of the above spectral decomposition methods, the input seismic data volume can be decomposed into amplitude and phase volumes at discrete frequencies within the bandwidth of the data. These discrete frequency volumes are sometimes also referred to as common frequency volumes.

Example

Here, we illustrate the S-transform application of the spectral decomposition method to a case study from western Canada. In Figure 1 we show a comparison of stratal slices through the seismic data (Figure 1a) and 40 Hz spectral decomposition volumes (Figure 1b). The stratal slices were chosen 16 ms below a marker seismic reflector close to 950 ms on seismic data processed with 5-D interpolation used to regularize offsets and azimuths. By design, the original broadband seismic data volume can be reconstructed by a weighted average of the individual component volumes, including the 40 Hz volume shown in Figure 1b.

Note there is greater lateral variation in seismic amplitude in Figure 1b, which in this case is directly related to tuning effects associated with a distributary channel. The comparison of the stratal slices just 4 ms below these slices is shown in Figure 2, where a channel system is seen clearly on the 40 Hz spectral slice (Figure 2b), which is not as clearly seen on the seismic amplitude slice (Figure 2a). Finally, the coherence attribute comparison on the two volumes is shown in Figure 3, where the definition of the individual channels is seen very clearly on the spectral slice.

Conclusion

Spectral decomposition is an effective way of analyzing the seismic response of stratigraphic geologic features. Because of tuning and the variation of the signal-to-noise ratio with frequency, alternative spectral components can provide significant insight into the stratigraphic interpretation.

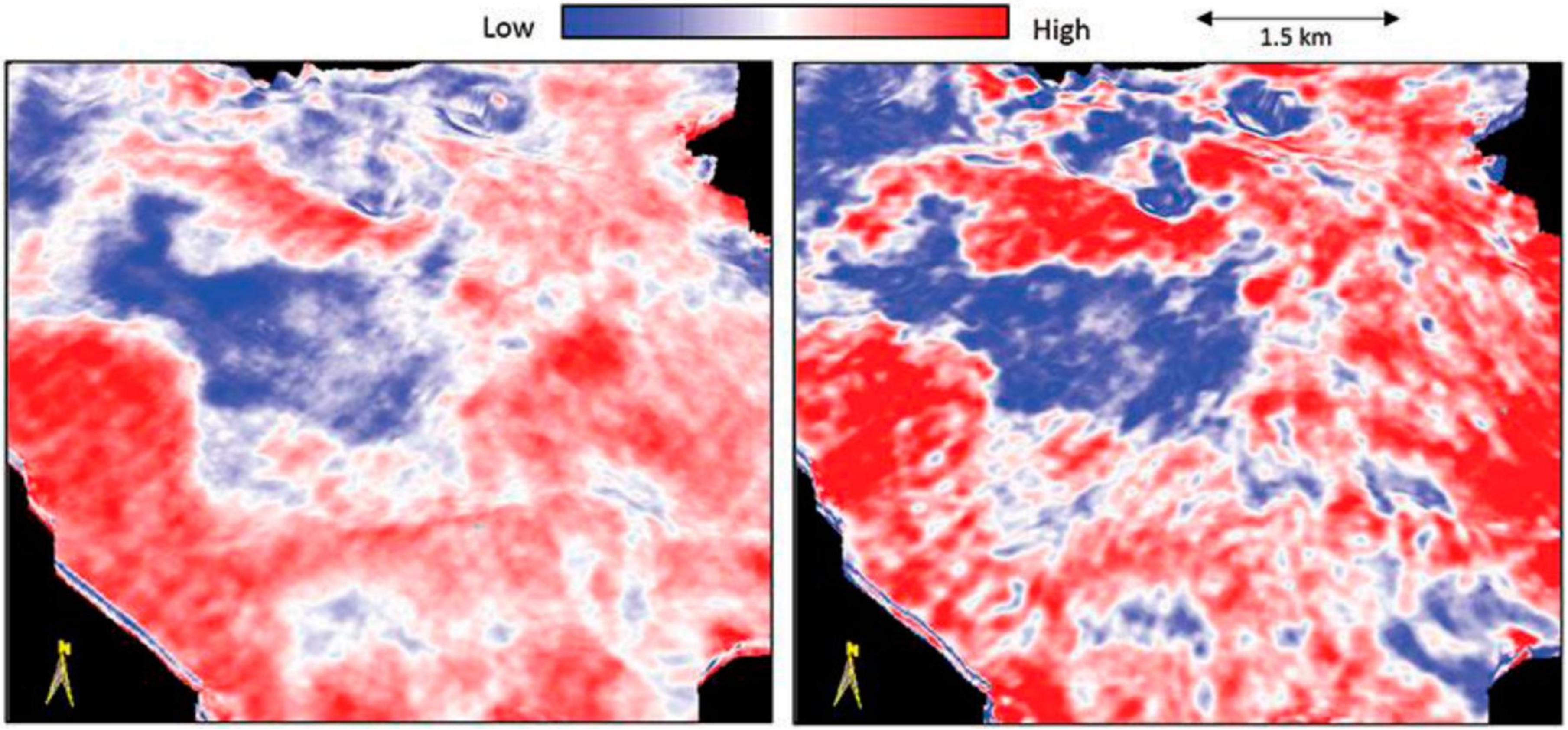

Figure 1. (a) Strat-slice 16 ms below a marker horizon at 950 ms from a seismic volume after 5-D interpolation. (b) Strat-slice 16 ms below a marker horizon at 950 ms from a 40 Hz seismic volume after 5-D interpolation and spectral decomposition.

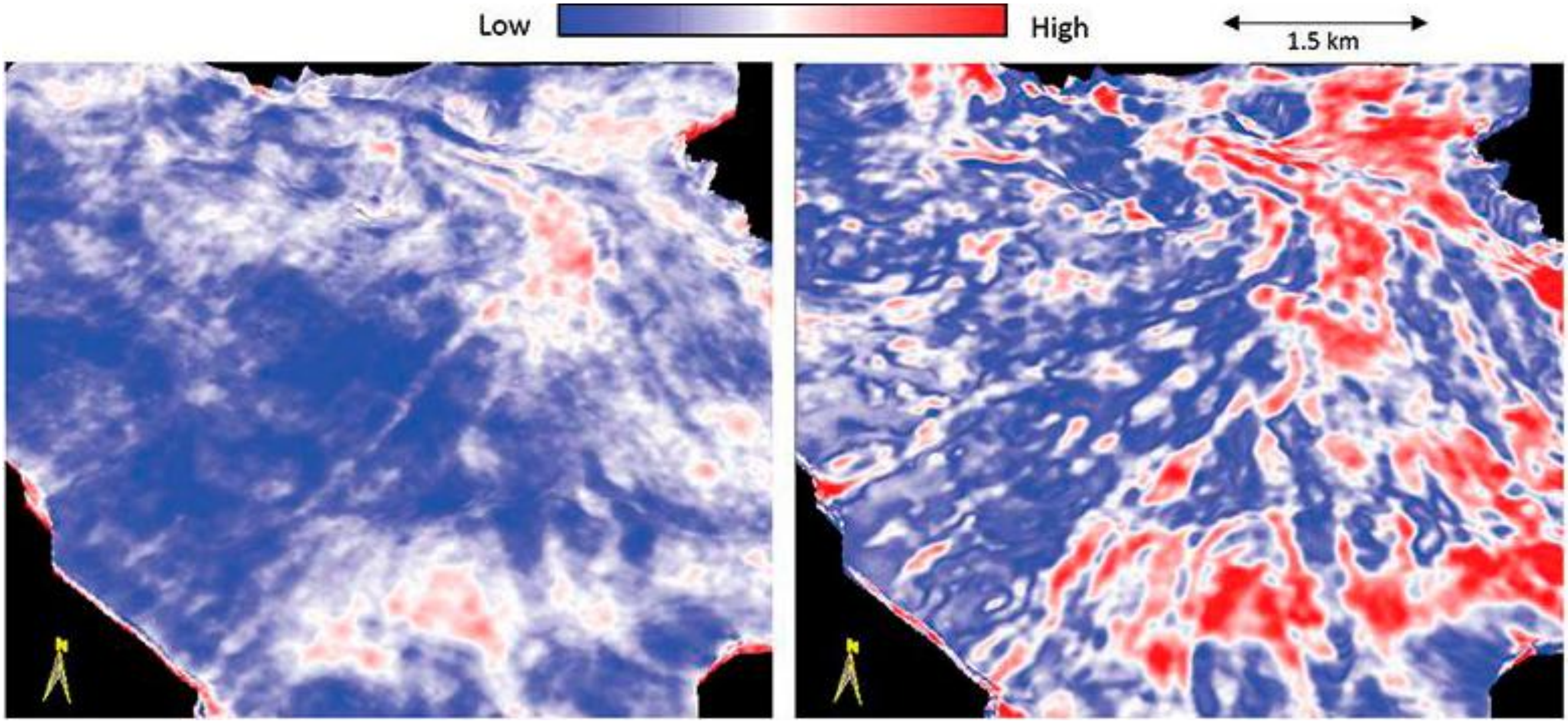

Figure 2. (a) Strat-slice 20 ms below a marker horizon at 950 ms from a seismic volume after 5-D interpolation. (b) Strat-slice 20 ms below a marker horizon at 950 ms from a 40 Hz seismic volume after 5-D interpolation and spectral decomposition.

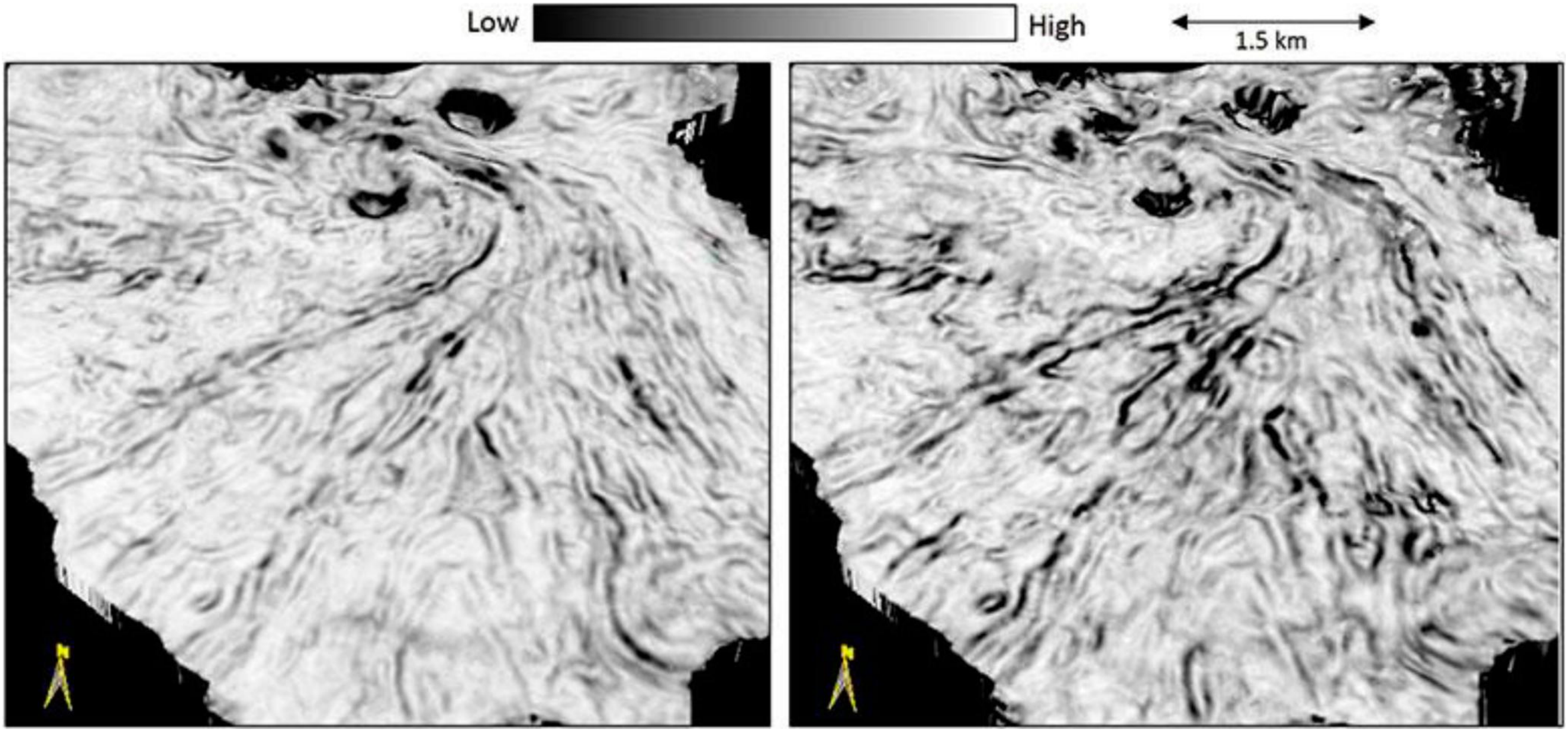

Figure 3. (a) Strat-slice from coherence volume run on seismic data after 5-D interpolation. (b) Strat-slice from coherence volume run on 40 Hz seismic volume after 5-D interpolation and spectral decomposition.