GCPhase Residules Can Help Define Channels*

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General Statement

Interpreters use phase each time they design a wavelet to tie seismic data to a well log synthetic. A 0-degree phase wavelet is symmetric with a positive peak, while a 180-degree phase wavelet is symmetric with a negative trough. Given a 0-degree phase source wavelet, thin beds give rise to ±90-degree phase wavelets.

Mathematicians define phase using a “complex” trace, which is simply a pair of traces:

1) The first trace is the measured seismic data, and forms the “real” part of the complex trace.

2) The second trace is the Hilbert transform of the measured data, and forms the imaginary part of the complex trace.

Note in Figure 1a that when the real part of the trace is positive, the imaginary part is a minus-to-plus zero crossing. In contrast, when the real part of the data is a minus-to-plus zero crossing, the Hilbert transform is a trough. This latter phenomenon allows us to use the “instantaneous” Hilbert transform to generate an amplitude map of a thin bed that was previously picked on the well log as zero crossing of the measured (or real) data.

Now let’s map both parts of the complex trace on the same plot. As you may remember from high school algebra, the real part is plotted against the x-axis and the imaginary part against the y-axis. We plot the same 100 ms (50 samples) of data “parametrically” on the complex plane.

Note in Figure 1b that the waveform progresses counterclockwise from sample to sample. We map this progression using the phase between the imaginary and real parts. If we use the arctangent to compute the phase, we encounter a 360-degree discontinuity each time we cross ±180 degrees (Figure 1c). Note how peaks and troughs in Figure 1a appear at 0 degrees and ±180 degrees in Figure 1c.

Now, if we computed the phase by hand, we would obtain the much more continuous phase shown in Figure1d, which is an "unwrapped" version of Figure 1c, and in this unwrapped image, note there is still a discontinuity at t=850 ms; however, this discontinuity is associated with waveform interference (geology) and not mathematics. Such discontinuities form the basis of the "thin-bed indicator" instantaneous attribute introduced 30 years ago.

The above discussion illustrates the concept of phase unwrapping and discontinuities based on the complex trace used in instantaneous attributes. A more precise analysis can be obtained by applying the same process to spectral components of the seismic data. Spectral decomposition is a well-established interpretation technique. The seismic data are decomposed into a suite of spectral components, say at intervals of five Hz.

Most commonly we use spectral magnitude components to map thin bed tuning, while some workers use them to estimate seismic attenuation, 1/Q. The phase components are less commonly used, but often delineate subtle faults. Here, we will show how the identification of discontinuities in the unwrapped instantaneous phase discussed above can be extended to unwrapped phase of spectral components.

Example

Let us illustrate the use of such discontinuities by applying them to the well-studied Stratton Field data volume acquired over a south Texas fluvial-deltaic system by the University of Texas Bureau of Economic Geology. In our Stratton Field example, thin channels give rise to tuning effects and subtle amplitude anomalies as shown in Figure 2a. While we can detect the channel system on time and horizon slices, they are difficult to see on vertical slices through the seismic amplitude data (Figure 3a). Determining the thickness of the channel on the seismic amplitude image is even more difficult. The corresponding slice through the instantaneous phase volume (Figure 3b) shows a subtle change, but again does not help delineate the channel.

One approach to improving this image is to unwrap the instantaneous phase volume (as we did in Figure 1d) and compute its vertical derivative, thereby highlighting phase discontinuities due to waveform interference (in this case geology). Our approach is based on the computation of phase residues of spectral components computed at five Hz intervals, which provides not only an image of waveform interference, but also a measure of our confidence in the interference pattern (provided by the corresponding spectral magnitude) and the frequency component at which it occurs.

Figure 3c shows this computation, where the hue component of color corresponds to the frequency of the discontinuity and the intensity or brightness to its strength. A block arrow clearly delineates the top and bottom of the channel. Figure 3d co-renders the phase residue image with the original seismic amplitude using 50 percent opacity.

Conclusion

Thin meandering channels are often visible on amplitude time slices (Figure 2). Phase residues add the third dimension. In the April AAPG Explorer Geophysical Corner (Search and Discovery Article #41141), our colleagues will show how phase residues provide a powerful tool for geobody extraction and interpretation.

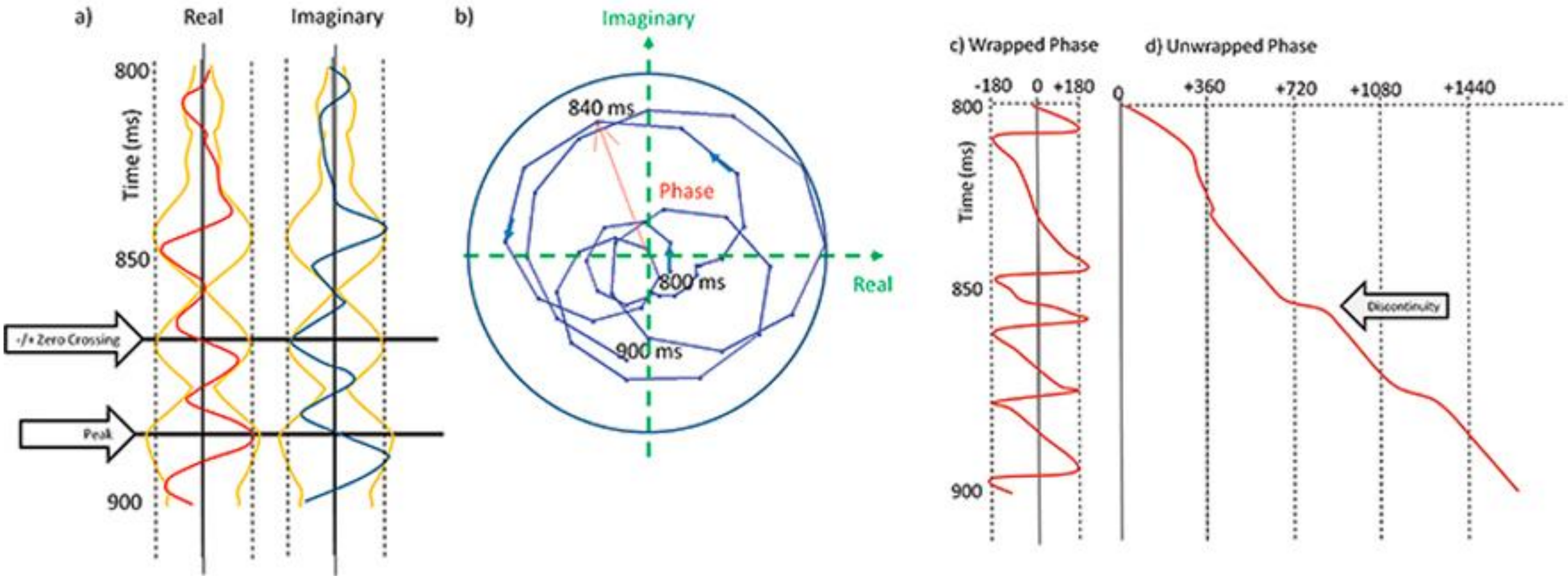

Figure 1. (a) The "complex" trace composed of the original measured trace, d(t), (the real part, in red) and its Hilbert transform, dH(t), (the imaginary part, in blue) extracted from the survey shown in Figure 2 and Figure 3. The envelope and its reverse are plotted in orange. Note how it "envelopes" the real and the imaginary trace (and indeed any phase-rotated version of the trace). (b) The complex trace plotted parametrically against time on a complex plot. Each time sample can also be represented in polar coordinates as a magnitude and phase, with phase being measured counterclockwise from the real axis. (c) The wrapped phase computed as φ=ATAN2[dH(t),d(t)]. The definition of the arctangent gives rise to discontinuities at ±1800. (d) The unwrapped phase, retaining only discontinuities associated with waveform interference (geology and crossing noise).

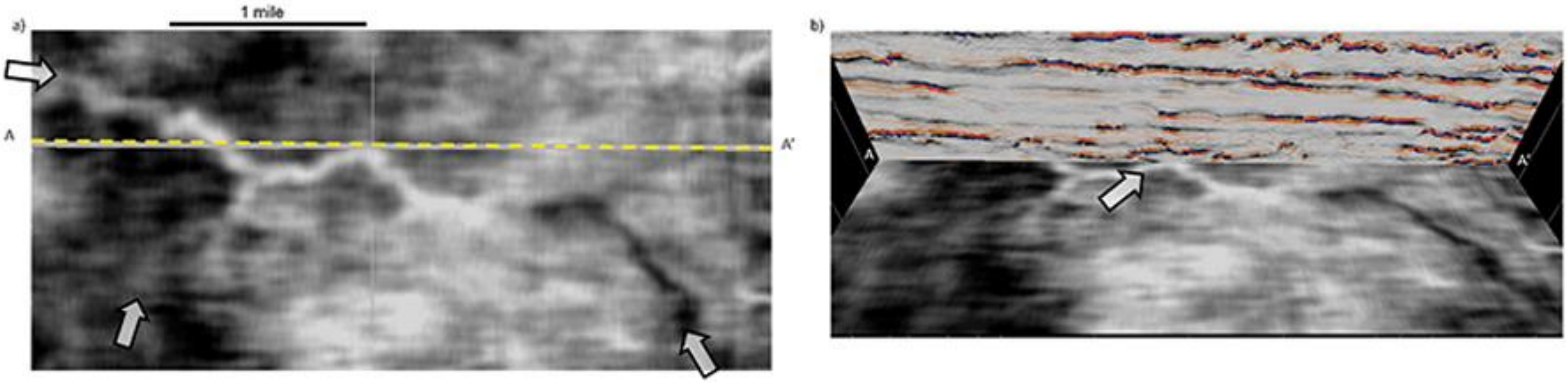

Figure 2. (a) A time slice at t=842 ms through a data volume acquired over Stratton Field, south Texas. Block arrow indicates a channel that gives rise to an amplitude anomaly. (b) The same time slice co-rendered with a vertical slice through the corresponding spectral phase residue volume. Seismic data courtesy of the University of Texas Bureau of Economic Geology.

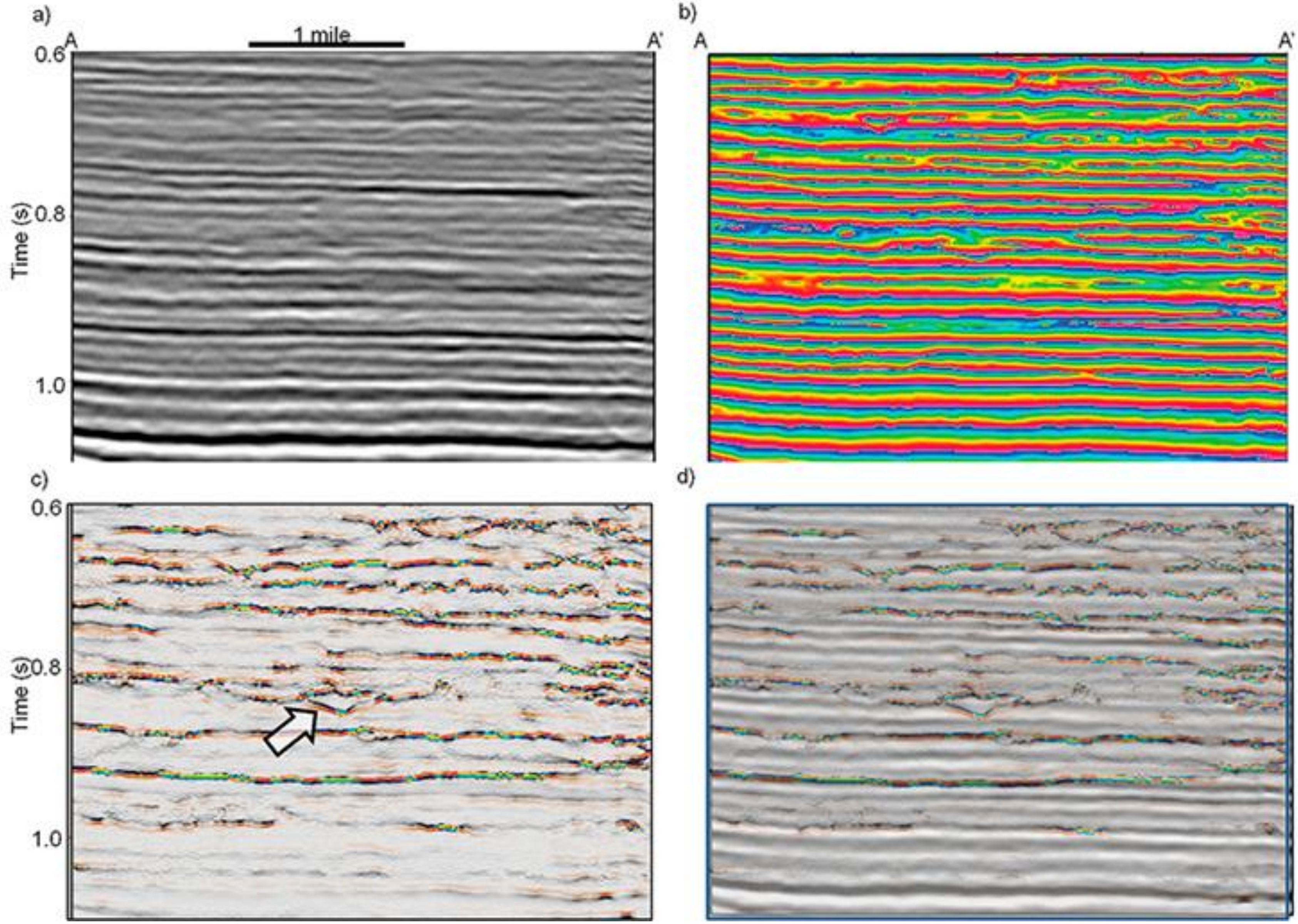

Figure 3. Vertical slices along line AA' shown in the previous image through (a) the seismic amplitude, (b) the instantaneous phase, (c) the phase residue, and (d) the co-rendered phase residue and seismic amplitude volumes. The instantaneous phase is plotted using a cyclical color bar. The phase residues are color coded by the magnitude and frequency of the spectral components at which they occur.