Using an HSV color map to visualize spectral phase and magnitude information for an incised valley system in the Anadarko Basin, Oklahoma, USA

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Summary

Spectral decomposition is a proven, useful tool for gaining understanding of complex geologic regions such as fluvial-deltaic systems and turbidites. Typically, interpreters focus on spectral magnitude while downplaying or ignoring phase. In this abstract, we present a visualization method that combines spectral phase and magnitude using a hue-saturation-value (HSV) color map and demonstrate application of this approach to mapping an incised valley system from the Anadarko Basin, Oklahoma, USA.

Introduction

Because it is sensitive to changes in thickness, spectral decomposition (Brolley, 1978) of seismic amplitude data is a powerful tool for tasks such as mapping channels, submarine fans, and other sedimentary features (Wallet, 2008). In the spectral decomposition process, a seismic amplitude trace is decomposed into time-varying frequency information. This process can be achieved by a number of means including the Discrete Fourier Transform (Partyka et al., 1999), continuous wavelet transform (Stockwell et al., 1997), and matching pursuit (Castagna et al., 2003; Liu and Marfurt, 2005). Each of these approaches has strengths and weaknesses according to the application, and numerous papers have compared their relative merits (Castagna and Sun, 2006; Leppard et al., 2010).

In a typical application, an interpreter will generate a moderate to large number of spectral attribute volumes. For instance, if an interpreter calculates components for 10 Hz–100 Hz in 1-Hz increments, the resultant data set contains 91 attributes. Furthermore, a given frequency, a spectral magnitude and phase component can be generated. This large amount of resulting data presents considerable challenges in terms of data management and visualization. Historically, an interpreter would display a single-magnitude component as a horizon slice, scrolling through frequencies to select the frequency that appeared to best delineate the architectural elements of interest. A number of differing approaches have been proposed in recent years to deal with this large amount of data. Johann et al. (2003) optically stacked the spectral components using 3D visualization. Guo et al. (2006) used principal component analysis (PCA) to reduce the dimensionality of the data. Wallet (2008) developed an interactive technique for searching for more optimal linear combinations of spectral magnitude components. Other possible approaches are Self-Organizing Maps (SOM), Generative Topographical Maps (GTM), and Diffusion Maps (Wallet et al., 2009).

Thus far, most interpreters have focused on using just the magnitude component from the spectral decomposition process. This is largely due to the well-understood relationship between spectral magnitude and tuning effects of feature thickness. In contrast, phase information is generally underutilized despite the fact that it can contain valuable information.

Dealing with both magnitude and phase information presents a number of problems. Beyond the difficulties previously discussed, incorporating phase information adds the additional complexity in visualization due to its circular nature. In this paper, we explore the use of a hue-saturation-value (HSV) color map to allow for the co-visualization of magnitude and phase. We then apply this approach to the visualization of an incised channel system in the Anadarko Basin, Oklahoma, USA.

Geological and Geophysical Background

For this work we focused upon a system of incised valleys and related architectural elements in the Red Fork Formation, Anadarko Basin, Oklahoma, USA. Pennsylvanian rocks throughout most of the Anadarko Basin are dominated by shallow shelf marine clastics. The Desmoinesian fluvial-deltaic and shallow marine play of north-central Oklahoma is the second largest Pennsylvanian play in the U.S. Midcontinent (Bebout et al., 1993). This play can be divided in two groups the Marmathon Group that comprises the Big and Oswego Limestones and the Cherokee Group that comprises the Skinner, Red Fork, Pure and Bartlesville Sands among other formations. These Desmoinesian sequences are the result of early Desmoinesian transgressions of the sea interrupted by several regressions of deltaic advances to the south of the Anadarko Basin (Bebout et al., 1993).

The Red Fork Formation in the study area is characterized by three coarsening upward marine parasequences referred to as Regional Red Fork, with the regionally extensive Pink Limestone above and the Inola and Novi Limestones below. Incised valleys of Lower, Middle, and Upper Red Fork age have eroded into these regionally correlative parasequences, forming a fluvial-deltaic complex trending east-west in the Anadarko Basin (Clement, 1991; Peyton et al., 1998). The Upper Red Fork incised valley system

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consists of multiple stages of incision and fill, resulting in a stratigraphically complex internal architecture (Peyton et al, 1998). The thickness for this reservoir varies from 35 to 64 ft. and porosity ranges from 7 to 14%.

The seismic data set we used was the result of merging three data sets shot by Amoco from 1993 to1996 and subsequently acquired by Chesapeake Energy in 1998 (Peyton et al., 1998). This data set had significant issues regarding acquisition footprint.

This particular data set has been the focus of a number of previous studies. Suarez et al. (2008) analyzed it using a number of seismic attributes, demonstrating improved ability to interpret various features. Wallet et al. (2009) examined various methods of latent space analysis to map seismic waveforms into a lower dimensional space for visualization.

For our work, we used a recently reprocessed version of this data set (Figure 1) that has significantly improved quality and considerably less acquisition footprint. From this data set, we interpreted the top of the Oswego Limestone which is above the Red Fork Formation. We then calculated spectral decomposition information including both magnitude and phase using software developed at the University of Oklahoma.

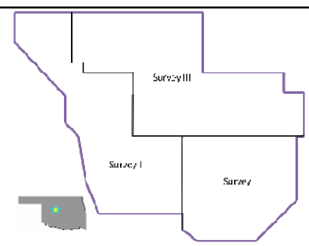

Figure 1: The data set used in this work was the result of merging three legacy data sets acquired by Amoco from 1993 to1996.

We then focused our study upon spectral components centered upon a horizon 60ms below the interpreted Oswego horizon (Figure 2). This horizon was chosen because it is well centered within the Red Fork Formation. Large channels are clearly present in this image though other features demonstrated in previous studies are less clearly visible.

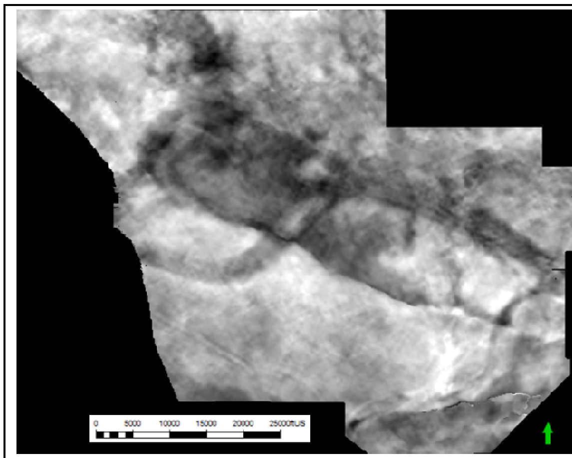

Figure 2: Phantom horizon slice 60ms below the interpreted Oswego horizon.

HSV Color Model

The HSV color model is an alternative conceptual color space to the commonly used RGB model. In the RGB model, colors are decomposed into three values representing human color perceptions of light spectra corresponding to red, green, and blue. The RGB color model thus arises from a biological model of three sets of spectrum-specific detectors (cones) in the typical human eye.

The HSV color model can be considered a reorganization of the RGB color model. A HSV color model consists of three components: hue, saturation, and value (or brightness). Hue appears as a periodic value displayed about a color wheel. Saturation appears as a purity of color: completely saturated points are pure colors, less-saturated values appear pastel, and completely unsaturated points appear white under full brightness. Brightness appears as the amount of illumination of the colors. Lower brightness points are dimmer and points of zero brightness are black. A cylindrical representation of the HSV color space is shown in Figure 3.

We note that the mapping from HSV to RGB is injective in that every point in HSV space maps to precisely one point in RGB space. However, it is not surjective since any point with zero saturation maps to a single point (white) in RGB space, and any point with zero brightness maps to a single point (black) in RGB space. This mapping can be made bijective by having zero saturation and/or zero brightness undefined for all but one point. The mapping then becomes discontinuous, and the sets would still not be topographically equivalent.

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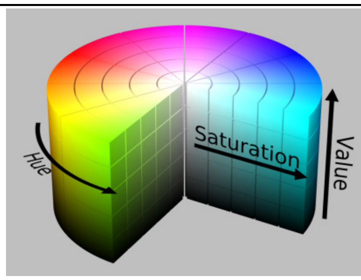

Figure 3: HSV is a cylindrical-coordinate color representation model. Hue represents a pure color about the cylinder. Saturation represents a purity of color ranging from white to a pure color. Value represents an illumination from black to a bright color. (Wikimedia Commons)

Methods and Application

We generated spectral magnitude and phase components for the data discussed. For the purposes of this study, we generated spectral components from 10 to 90 Hz at 10-Hz increments.

Before looking at alternative methods of visualization, we first considered the canonical methods. As we stated previously, interpreters to date have focused solely on spectral magnitude. Apart from viewing each frequency as a grayscale image, the simplest approach is to view three frequencies of spectral magnitude data as an RGB blended image. The result of this approach for 20, 40, and 60 Hz is shown in Figure 4.

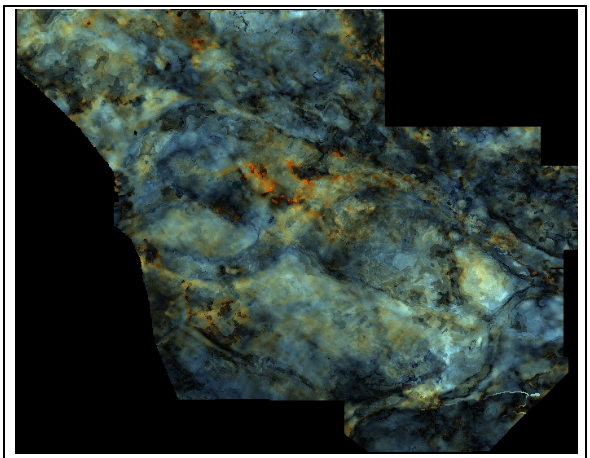

Figure 4: RGB visualization of spectral magnitude for 20, 40, and 60 Hz as red, green, and blue, respectively.

Alternatively, Guo et al. (2006) applied principal component analysis (PCA) to spectral magnitude data and then visualized the first three principal components using an RGB display. The results of this analysis are shown in Figure 5.

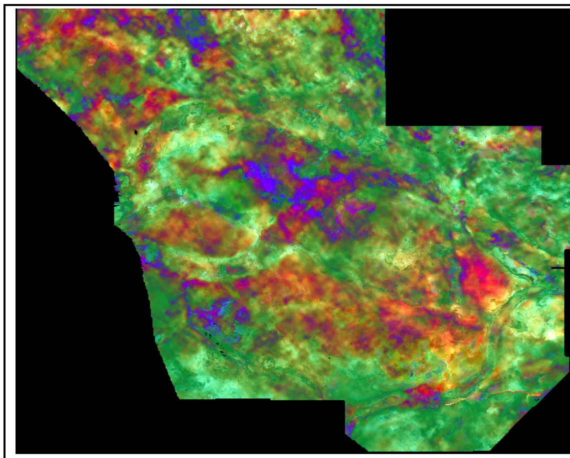

Figure 5: RGB visualization of the first three principal components mapped into red, green, and blue, respectively.

Proper visualization of the phase is more complex. The circular nature of phase makes it unsuitable for visualization using either an RGB color map or a grayscale color map. A reasonable approach to the visualization of spectral phase is by using a color wheel (Figure 6).

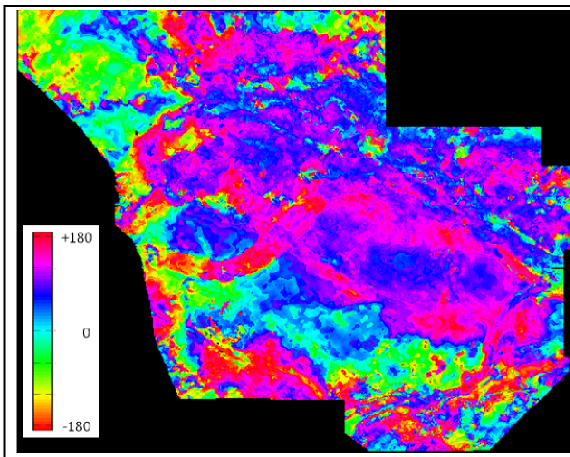

Figure 6: Spectral phase information for 40 Hz shown using a color wheel to correctly display the attribute's circular nature.

A possible approach to combining spectral magnitude and phase is through the use of an HSV color map. In such a visualization scheme, hue would be the natural choice for representing phase. However, the choice between saturation and value for magnitude might be considered arbitrary. Based on past experience, we chose to represent magnitude

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using value. Furthermore, our experience shows the use of full saturation tends to lead to images that are overly harsh in their character, making them difficult to interpret. To improve the aesthetics of the visualization, we thus chose to use a static saturation of 0.4, resulting in an image that is more pastel in nature (Figure 7).

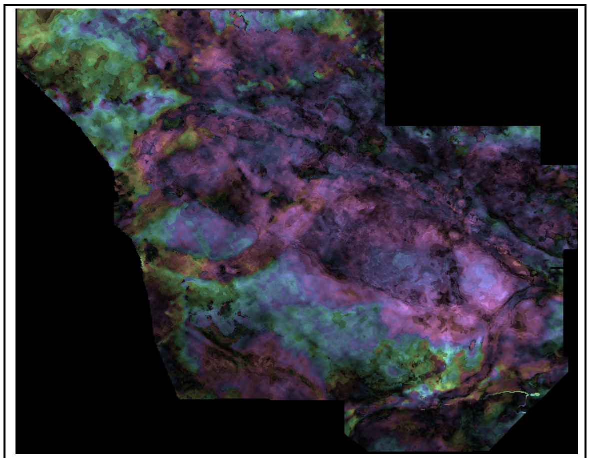

Figure 7: Spectral phase and magnitude for 40 Hz displayed using an HSV color map. Phase is encoded as hue, magnitude is encoded as value, and saturation is a constant 0.4.

As an additional enhancement, we tried a number of approaches to utilizing the saturation channel to convey additional information. Figure 8 shows the 40-Hz image from Figure 7 with the saturation channel partially modulated using the output of a Sobel filter. We believe this image is slightly more useful in interpreting subtle channel features, though this is admittedly subjective.

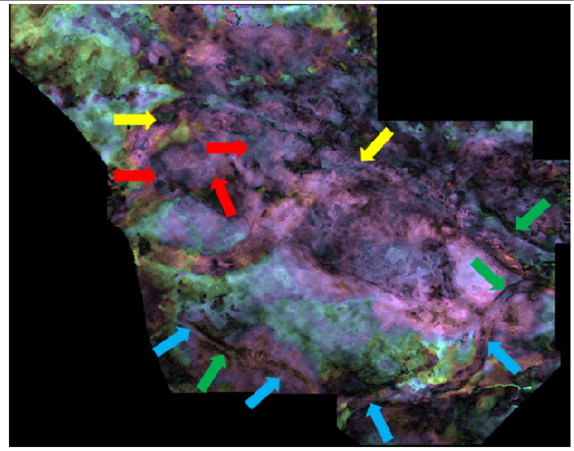

Figure 8: Spectral phase and magnitude for 40 Hz displayed using an HSV color map. Phase is encoded as hue, magnitude is encoded as value, and saturation is used to enhance edges using information from a Sobel filter. Blue arrows denote large, meandering channels; red arrows denote valley infill; and yellow arrows show elements that correlate with known shalier infill of large channel features.

Conclusions

We have shown a method for co-visualizing spectral phase and magnitude information using a HSV color map. This method leads to rich images with considerable detail. We have further demonstrated the use of the saturation channel in incorporating spatially enhanced information from the results of a Sobel filter. We believe this method adds positively to the methods available to interpreters looking at spectral decomposition attributes.

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