geoconvention
Calgary • Canada • May 15-17 2023

Amplitude Versus Frequency

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Summary

Spectral decomposition has played a significant role in seismic interpretation to help geoscientists understand subsurface conditions. Various approaches have been proposed and have focused on spectral decomposition resolution and robustness. In this paper, we propose a technique called amplitude versus frequency (AVF), an effective and fast application of spectral decomposition. Regardless of what kind of spectral decomposition method is used, the AVF attributes will highlight the attenuation features in the seismic data, therefore displaying valuable information for seismic interpretation.

Introduction

Spectral decomposition has been utilized for over a decade and has been successfully applied in seismic interpretation and reservoir characterization. The objective of spectral decomposition is to describe how the frequency content varies with time, by mapping a 1D time signal into a 2D image of frequency and time. From traditional spectral decomposition methods, like the short-time Fourier transform (STFT), the continuous wavelet transform (CWT) and the S-transform, to high-resolution methods like basis pursuit (BP), empirical mode decomposition (EMD) and the synchrosqueezing transform (SST), research has focused on improving the time-frequency resolution and robustness and minimizing spectral smearing (Han and van der Baan, 2013; Herrera et al., 2013; Tary et al., 2014). By utilizing the frequency content of seismic data using spectral decomposition techniques there have been many successful applications. Castagna et al., (2003) analyzed low-frequency features for detecting potential hydrocarbon reservoirs, Han and van der Baan (2013) interpreted reservoir thickness variation by comparing iso-frequency slices, Li and Lu, (2014) calculated the coherence attribute on different spectral scales to highlight geological features. Recently, Zhao et al. (2021) applied frequency-dependent amplitude versus offset (AVO) for thin-bed identification.

In this paper, we show an application of spectral decomposition, which we call amplitude versus frequency (AVF), that highlights the attenuation variation in seismic data. AVF can use the output from any spectral decomposition method, and the output attributes perform well on real data examples.

Method

Attenuation refers to the loss of energy as a wave propagates through a given medium. This leads to a certain amount of energy loss per period, which defines the quality factor Q. For seismic applications, the accurate estimation of the Q value is challenging due to complex factors such as spherical divergence, scattering, intrinsic absorption and reflection at formation interfaces (Tary et al., 2017). AVF delineates the attenuation variation in the seismic data without calculating the Q value and is applied to post-stack data.

Numerous researchers have observed the difference in frequency content between hydrocarbon and non-hydrocarbon areas in field data. Due to the higher attenuation of fluid properties inside the formation, frequency content in the hydrocarbon area usually displays decreasing frequency bandwidth and a dominant frequency shift towards the lower frequency. Chabyshova and Goloshubin (2014) used a reservoir model with typical sandstone parameters to interpret this mechanism. Based on this observation, Mandong et al., (2021) and Wihardy and Khairy (2021) attempted to use a regression line similar to Shuey's 2-term approximation from Aki-Richard's formula, to fit the amplitude variation from spectral decomposition, therefore quantifying this phenomenon.

The AVF method proposed in this paper involves two steps. In the first step, we generate a frequency gather using the spectral decomposition technique. Figure 1 shows a frequency gather computed from the continuous wavelet transform (CWT), and each subfigure is the time-frequency distribution for each seismic trace. The x-axis is the frequency and the y-axis is time. The CWT offers detailed frequency information for each time sample of the seismic signal. In the second step we fit the amplitude variation with frequency using equation (1) for each time sample. Note that we use a linear equation to fit the spectral amplitude with frequency, instead of the square of the sine function of frequency which is used in the papers of Mandong et al., (2021) and Wihardy and Khairy (2021). The equation is

$$A(f) = I + G * f \tag{1}$$

where $A(f)$ is the amplitude value from the spectral decomposition, I is the intercept, G is the gradient, and f is the frequency. By fitting the curve in the desired frequency range, I and G can be calculated to depict the attenuation variation in the seismic data. The intercept I, gradient G and the product of them are called the AVF attributes in this paper.

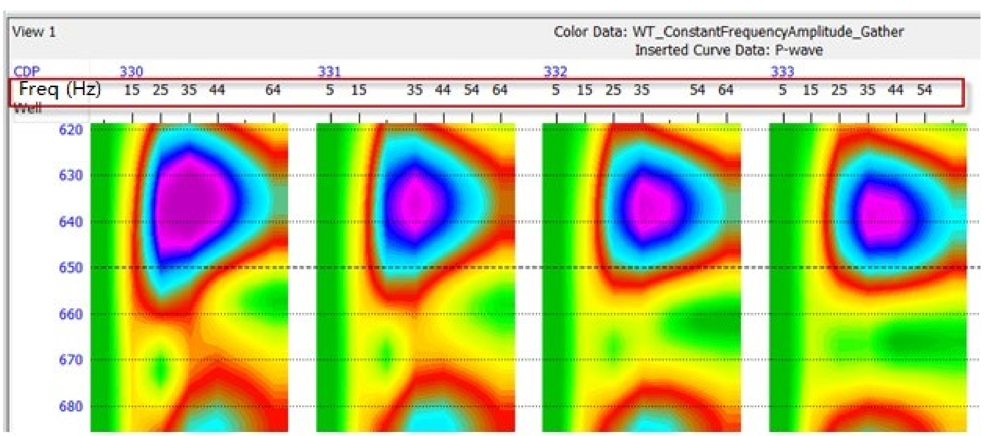

Figure 1: Frequency gather from the continuous wavelet transform (CWT).

To estimate the AVF attributes accurately, the frequency range is the key parameter in this approach. The terms *f1* and *f2* in Figure 2 indicate the start and end frequency points for calculating the AVF attributes. In our applications, the dominant frequency from the spectral decomposition is a good value for the start frequency, and the end frequency can be determined by the user based on the amplitude spectrum shape or range. Figure 2 simulates the amplitude variation from the spectral decomposition for both hydrocarbon and non-hydrocarbon areas. The hydrocarbon area (red curve in Figure 2) usually has a larger intercept and a more steep gradient due to the stronger attenuation compared with the non-hydrocarbon area (blue curve in Figure 2).

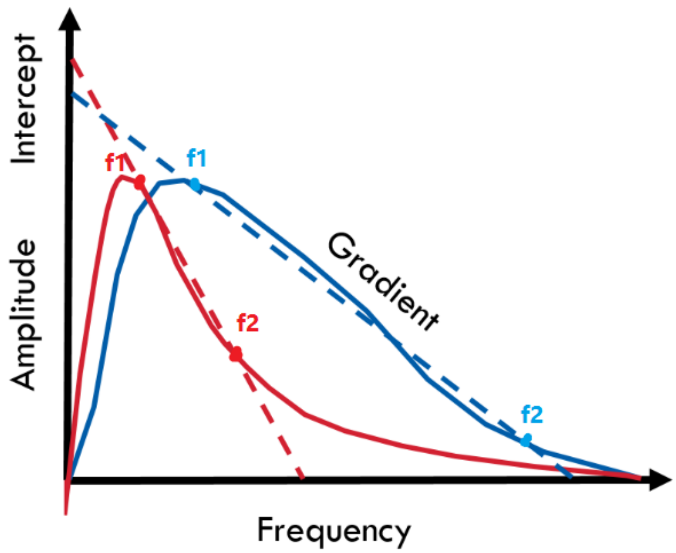

Figure 2: AVF gradient and intercept are calculated by fitting the linear slope for the amplitude information from spectral decomposition in the frequency range [*f1, f2*] (Wihardy and Khairy, 2021). The red line simulates the spectral variation in the hydrocarbon area; while the blue line simulates the spectral variation in the non-hydrocarbon area. The hydrocarbon area usually has a larger intercept and a more steep gradient due to the stronger attenuation.

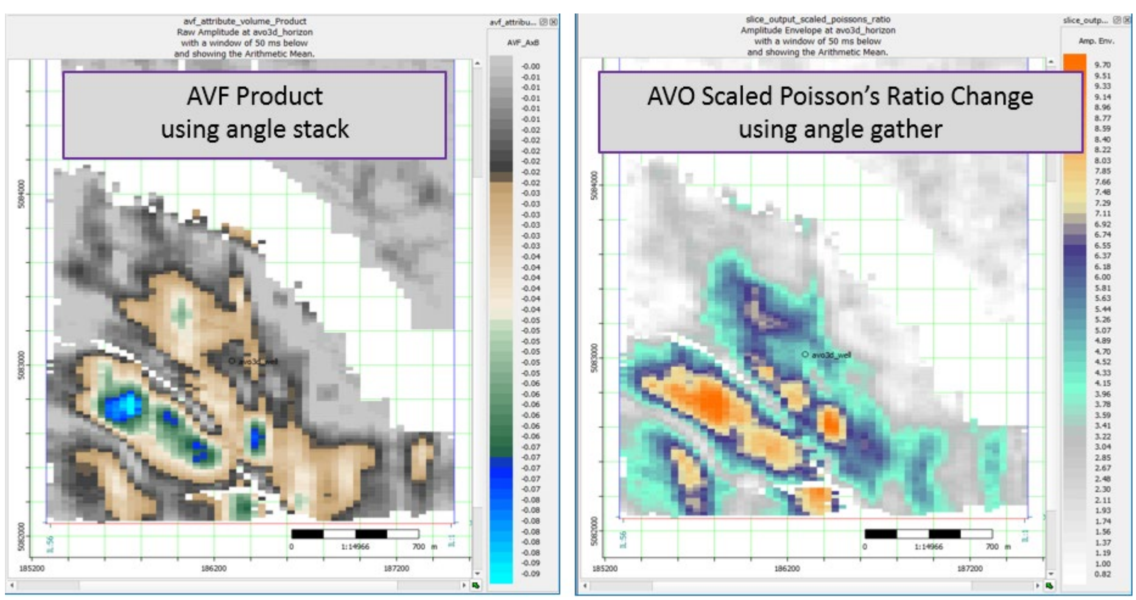

Figure 3: Colony gas sand dataset. Left: AVF product using stack data; Right: AVO scaled Poisson's ratio using angle gather.

Examples

The first example is the Colony dataset from Canada. Figure 3 left shows the AVF product from the continuous wavelet transform, and Figure 3 right is the AVO scaled Poisson's ratio using angle gather. In this example, the AVO scaled Poisson's ratio acts as the benchmark result for validating the AVF result. The AVF anomaly is consistent with the AVO anomaly in this dataset, showing a potential location for the gas sand. One main advantage of AVF is that the approach only requires post-stack data. This is an attractive feature when the gather is not accessible or gather quality is not optimal in the project.

The second example is the well-published dataset from the Netherlands North Sea. Figure 4 left is the frequency gather computed from the basis pursuit (Tary et al., 2014; Han et al., 2017), which is a high-resolution spectral decomposition method. Figure 4 right shows the AVF intercept. Benefiting from the high resolution, the AVF intercept aligns well with the geological structure. A more obvious result can be found on the time slice (Figure 5), the AVF anomaly is highlighted in the red circle, therefore indicating the attenuation variation in the seismic data accurately.

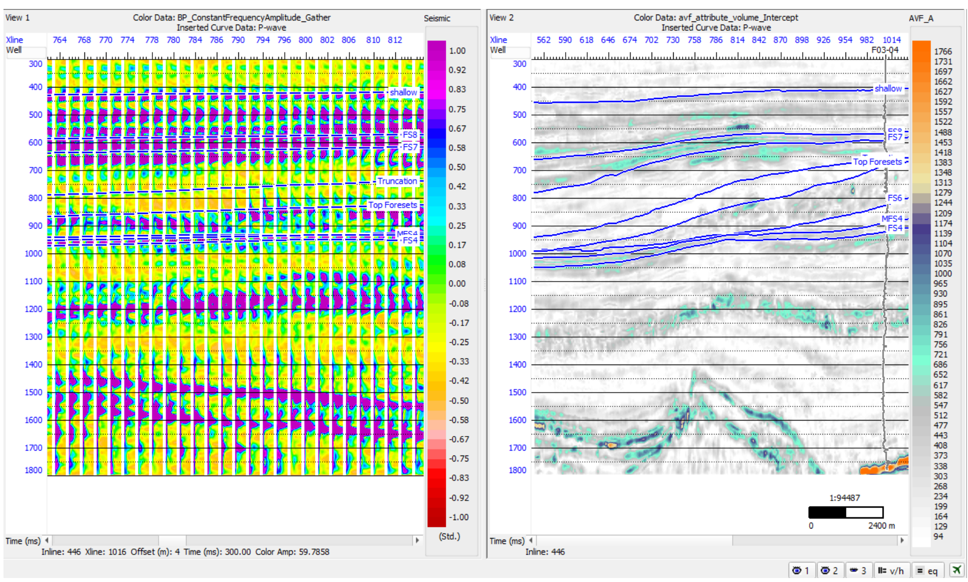

Figure 4: Netherlands North Sea dataset. Left: frequency gather generated from the basis pursuit; Right: AVF intercept.

Conclusions

The AVF method is an effective and fast application of spectral decomposition. By fitting the amplitude information from spectral decomposition, the AVF process quantifies the attenuation variation in the seismic data. Theoretically, every spectral decomposition method can be used as input for the AVF approach, and AVF only uses the post-stack data. These features make AVF attractive when there is limited gather information or gather quality is not optimal. The real data examples shown here illustrate the potential of the AVF approach.

Acknowledgments

The authors thank GeoSoftware for permission to show the case data examples.

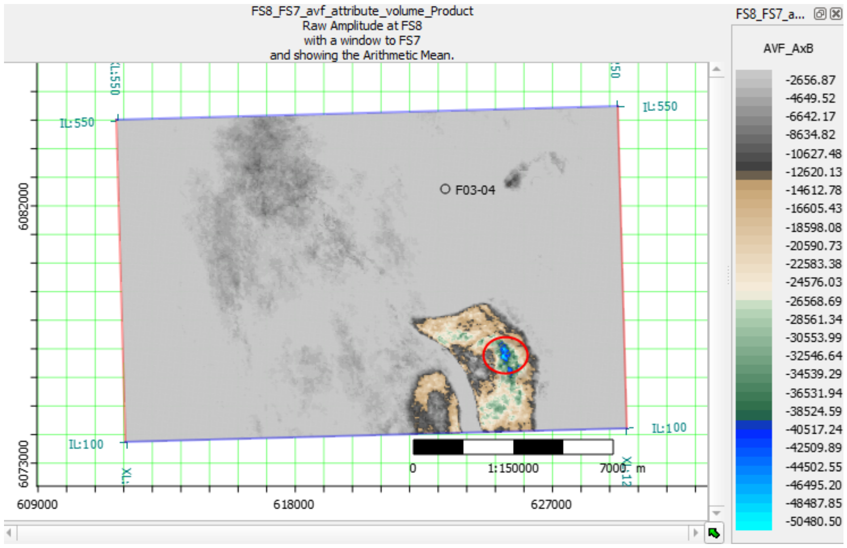

Figure 5: Time slice of AVF product on the Netherlands North Sea dataset. The red circle highlights the potential gas reservoir.

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