Improving reservoir geometry by integrating continuous wavelet transform seismic attributes

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Summary

Seismic interpretation is highly dependent of the seismic resolution. Sequence stratigraphy, fractures detection, faults interpretation and channels delineation can be improved by using better resolution seismic data. Considering spectral decomposition a way increase seismic traces details, we used complex continuous wavelet transform (CWT) ridges to create a higher resolution traces and the CWT phase interferences, or residues, to detect subtle seismic discontinuities. By integrating these seismic attributes we showed how to improve the understanding of reservoir geometry. The technique was applied to real data and using calibration wells we confirmed the effectiveness of the proposed methodology.

Introduction

Signal spectrum has been used since the primordium of the seismic acquisition for different purposes. Random and coherent noise filtering, spectral balancing and seismic wavelet shaping for deconvolution purposes are for instance among Fourier frequency analysis applications.

By using a small time window around the target area, Partyka et al. (1999) showed how spectral decomposition can be used to detect thickness changes and proved to be an important seismic interpretation tool. By using a running window spectral analysis, also called Short-time Fourier transform (STFT), we can extend the spectral analysis to the whole cube, by adding a 4th dimension, frequency, to the 3D seismic cube (Chopra and Marfurt, 2007). Actually, instead of STFT, we can use any other time-frequency decomposition, that converts seismic traces into 2D matrix that expresses how signals vary jointly along time and frequency. This redundant representation carries a lot of information and it is very dependent on the technique chosen. In this work, we use complex Continuous Wavelet Transform (CWT). Using the CWT advantage to detect transients, we used CWT spectral ridges to create a higher time (depth) resolution seismic trace and the CWT phase spectra to detect interferences between layers.

We begin our proposition by reviewing complex CWT attributes theory. Then we show how we can improve seismic interpretation by using the proposed methodology to both synthetic and real seismic data.

The methodology

The CWT is defined as the cross-correlation between the seismic trace and dilated versions of a basic wavelet (Grossman and Morlet, 1984). If the basic wavelet is symmetric the CWT can be construed by convolving the seismic trace with the time-reversed scaled version of the basic wavelet. Knowing convolution in time domain is equivalent to a product in the frequency domain (Oppenheim et al., 1999), CWT can also be interpreted as a band pass filtering or spectral decomposition process.

Therefore, after the CWT computation, each seismic trace is represented by a time (depth) versus scale (frequency band) complex matrix. This represents how well the seismic trace correlates to each dilated wavelet at each instant of time (Matos and Marfurt, 2011).

Mallat and Zhong (1992) showed that the CWT ridges along the scales are associated with signal inflection points and can be used to characterize them. They also showed we can reconstruct a non unique but very good approximation of the seismic trace by using only the CWT ridges, which they called Wavelet Transform Modulus Maxima Line Amplitudes (WTMML). Tu and Hwang (2005) later proved that the same concept can be applied using complex basic wavelets. As originally showed by Grossman and Morlet (1984), the complex CWT magnitude represents the average of the dilated wavelets at each instant of time. Consequently, the maximum averages, or the ridges, along the scales (WTMMLA) show the existence of consistent signal transitions.

Borrowing CWT spectral ridges (WTMMLA) ideas from Mallat and Zhong (1984), and Tu and Hwang (2005), geoscientists showed how CWT spectral ridges can be associated with reflectivity series (Hermann and Stark, 2000; Matos et al, 2007; Li and Liner, 2008, Devi and Schwab, 2009).

Matos and Marfut (2011) showed how to enhance seismic resolution by using complex Morlet CWT spectral ridges and reconstructing the seismic trace using a narrow band wavelet than the one used for analysis. This process is schematically shown in Figure 1.

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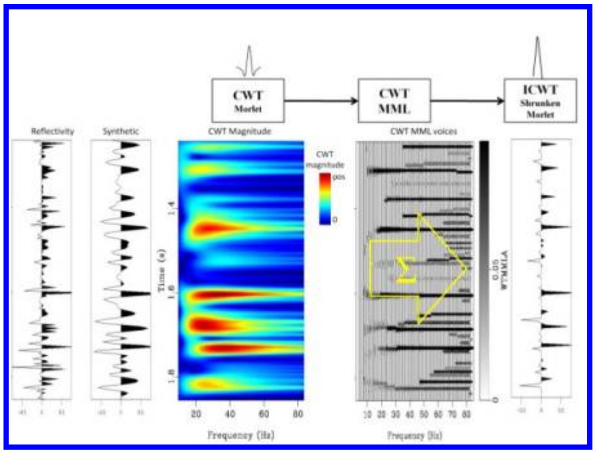

Figure 1:Schematically shows how to compute CWT enhanced resolution seismic trace.

Figure 2 shows a single 2D synthetic seismic response of a channel with thickness varying from 1 to 50 ms and Figure 3a shows the high resolution result. We can clearly see the improvement in the seismic resolution. Figure 3b shows the relative acoustic impedance computed from Figure 3a enhanced resolution trace.

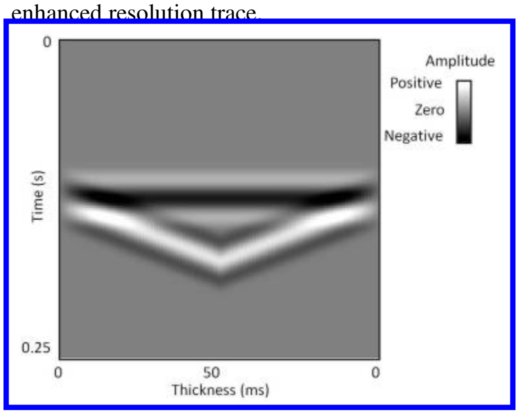

Figure 2:Synthetic channel model.

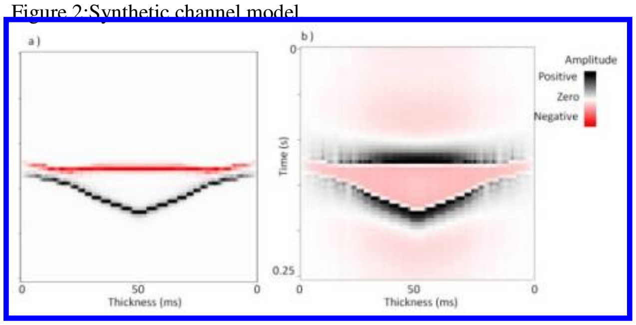

Figure 3: (a) Enhanced seismic resolution obtained by complex CWT and (b) its relative acoustic impedance.

Considering this high resolution seismic representation can be considered a reflectivity approximation, we can also estimate the relative acoustic impedance (RAI) by integrating the high resolution seismic trace (Berteussen and Ursin, 1983). Actually, the RAI computation consists of three steps:

1- Rescale the high resolution trace, by keeping the magnitude much smaller (we suggest 10 times) than one;

2 – Integrate the trace by using a special band pass filter (Peacock, 1979);

3 – High pass (we suggest 10 Hz) the integrated data.

Despite the complex CWT phase is used to reconstruct the high resolution trace, it also shows when one shifted and dilated wavelet interfere with each other. This interference or inconsistency is also called as phase residues (Bone, 1991) and Matos et al. (2011) showed how to use them to detect subtle discontinuities. Figure 4 shows that phase residues detected the channel edges when applied to the same Figure 2 wedge model.

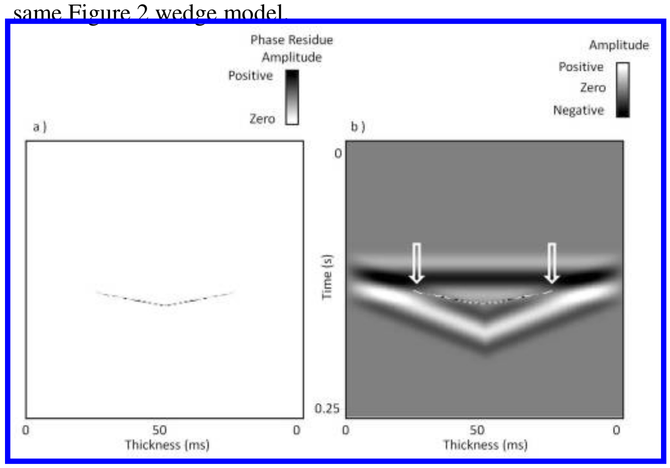

Figure 4: (a) Phase residue amplitude and (b) Seismic channel model corendered with CWT phase residue attribute.

Comparing Figures 3 and 4 we can clearly see how complementary CWT phase residues, high resolution spectral ridges reconstructed trace and relative acoustic impedance are for seismic interpretation purpose.

Case study Diamond M data set

Diamond M data set consist of approximately 25 mi^2 of seismic data with a high signal to noise ratio. The data comprises a complete stratigraphic sequence going from shallow marine carbonates (Horse Shoe Atoll), followed by progradation and regression sequences (Figure 5).

We have computed the CWT attributes to the Diamond M dataset in order to test the ability of the attributes to better define the stratigraphic sequences in interpreted (Figure 5). Figure 6 shows a composite of the seismic data and the enhanced seismic resolution CWT attributes for the

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Diamond M dataset. Figure 7 shows an extracted geobody that correlated to a complete progradation – regression cycle in the Diamond M dataset.

Conclusions

We show how CWT attributes can be effectively applied to reveal and enhance important stratigraphic features otherwise not revealed by conventional seismic amplitude. We have developed a workflow that combined seismic amplitude with CWT attributes in order to produce a high frequency seismic stratigraphy framework for seismic interpretation and demonstrate how by combining these attributes detailed seismic stratigraphy sequences can be extracted from the seismic data as an input for detailed reservoir characterization.

Acknowledgments

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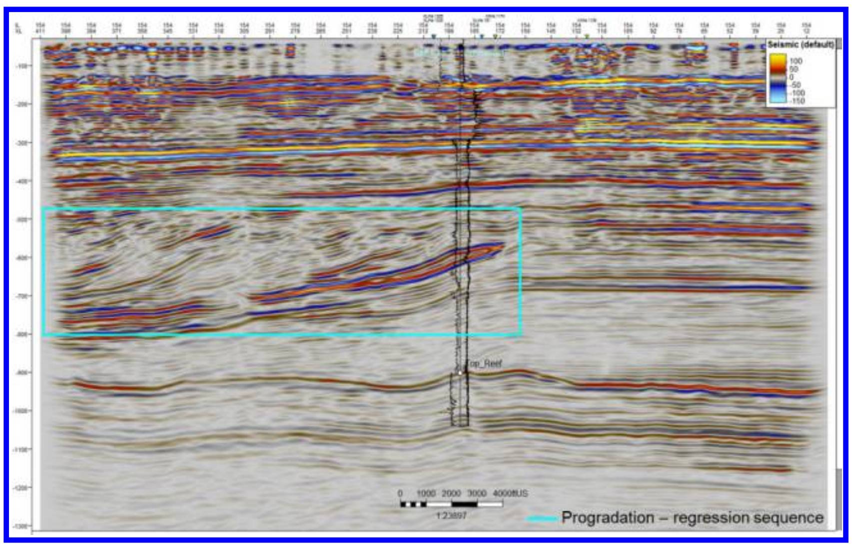

Figure 5: Representative seismic cross section trough the Diamond M data set. Cyan box indicates what is interpreted as clinoforms in a progradation – regression sequence. The well is displayed for reference. Continous pattern log is the bulk density log and the dotted pattern log is the photo electric factor log.

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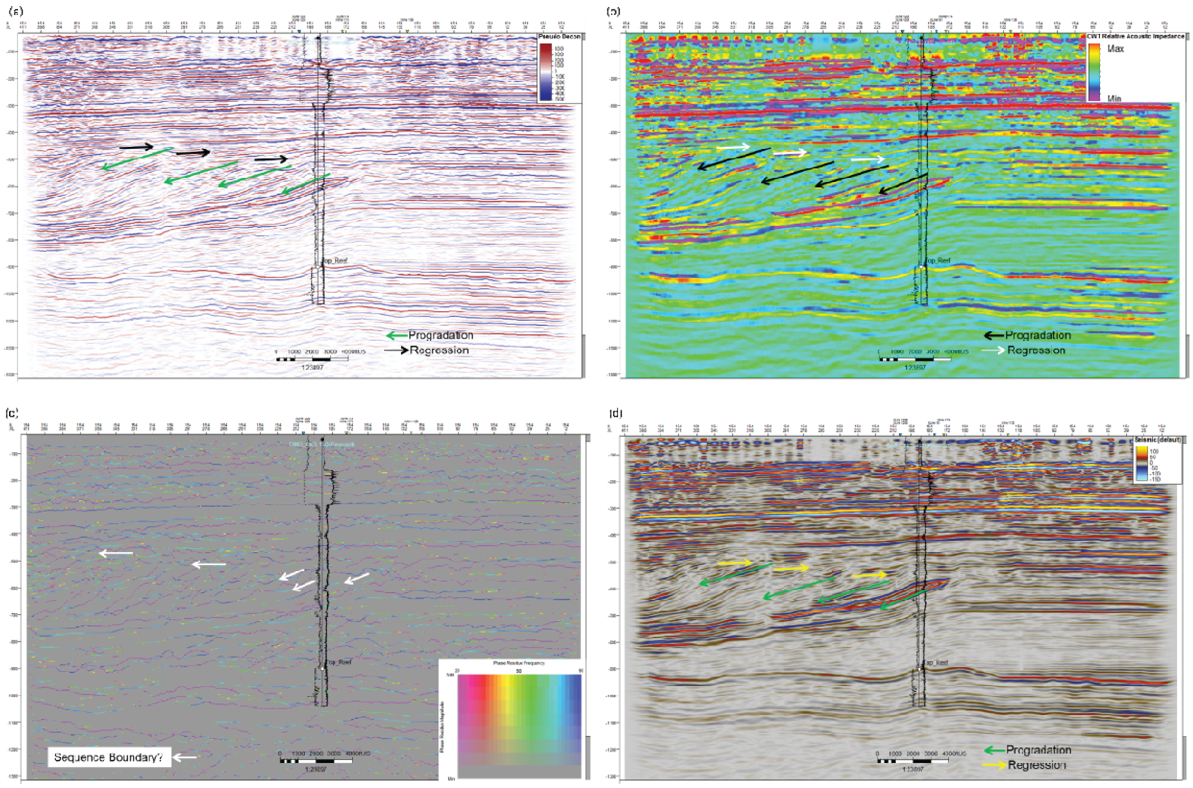

Figure 6: Representative seismic cross section trough (a) CWT pseudo deconvolution, (b) CWT relative acoustic impedance, (c) CWT phase residues and (d) seismic amplitude in the Diamond M data set. CWT attributes facilitate the interpretation of the sequences in show in Figure 5.

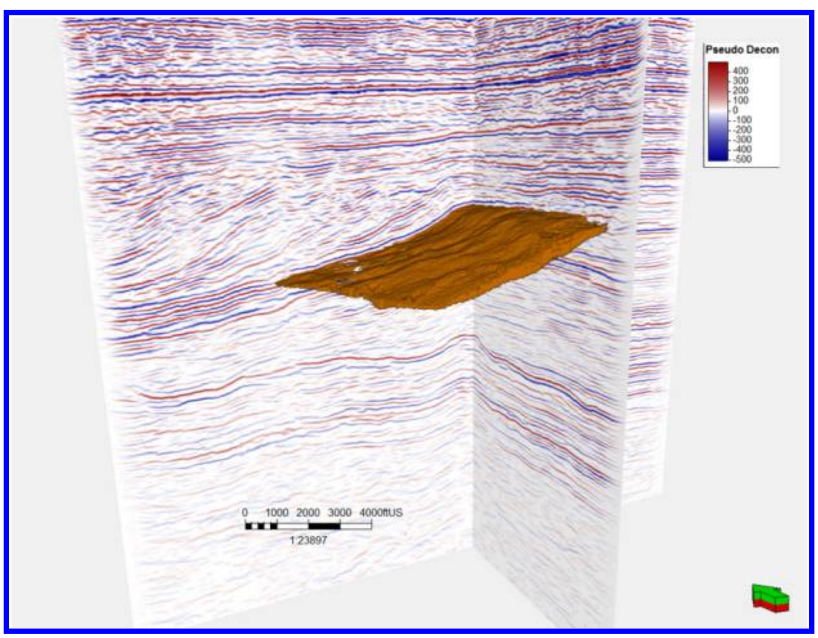

Figure 7: Extracted geobody of what it is interpreted as a progression – regression using the CWT attributes

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