*Detection of Hydrocarbons from Velocity Logs using the Wavelet Coherence Analysis: A Case Study from Algerian Tight Reservoirs

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Abstract

This study presents new insights on investigating hydrocarbon reservoirs using P- and S-wave velocity well logs (Vp and Vs) recorded in Algerian tight reservoirs. The proposed method is based on a time-frequency analysis, especially the wavelet coherence (WTC) that exploits the inherent phase information using the complex Morlet wavelet.

This analysis leads to valuable information about dynamic correlation and its impact on depth scales. The scalograms of the wavelet coherence phase, derived from Vp and Vs logs measured in different wells exhibit the spatial variability of correlation and phase shift against depth and scale (or wavenumber), and show a weak wavelet coherence at large scales (or small wavenumbers) for hydrocarbon-bearing formations. These preliminary results are very encouraging, and more applications should be carried out to validate the wavelet coherence-based analysis.

To conclude, the suggested method could be of great interest to detect the presence of hydrocarbons from velocity well logs.

Keywords: wavelet coherence, time-frequency analysis, velocity well logs, Algerian tight reservoir

Extended Abstract

Well log data are key elements in hydrocarbon reservoir characterization. Their interpretation allows extracting valuable information regarding the different reservoir properties (lithology, fluid presence, etc.). However, under certain circumstances, the conventional interpretation tools lead to inadequate results, and need to be supported by other analysis approaches. In this view, many techniques have been suggested (Gaci and Zaourar, 2010, 2011;Gaci et al., 2010, 2011; Honório et al., 2012; Partovi and Sadeghnejad; 2017; Amoura et al., 2019; Boulassel et al., 2021; Gaci and Nicolis, 2021). Here, a time-frequency analysis, based on the wavelet transform coherence (WTC) has been applied on well velocity log data.

The analyzed velocity (Vp and Vs) logs are measured in four exploration wells (W1, W2, W3 and W4) drilled in the southeastern Algerian basin. Our investigation was focused on depth intervals corresponding to similar shaly sandstone Devonian (Upper Triassic) and Silurian reservoirs: 2650-3400 m for wells W1 and W2, 2850-3400 m for well W3, and 2500-3200 m for the well W4.

Methods

The Continuous Wavelet Transform (CWT) is used to decompose time series x, with respect to two parameters: time (τ) and scale (a >0), into elementary functions derived from a mother wavelet ψ (Holschneider , 1995).

$$C_x(a,\tau) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t).\psi\left(\frac{t-\tau}{a}\right)\mathrm{d}t. \qquad (1)$$

where $\frac{1}{\sqrt{a}}$ is the normalization factor, ensuring that the unit variance of the wavelet $\int_{-\infty}^{+\infty} \left|\psi_{a,\tau}(t)\right|^2 \mathrm{d}t = 1$ for all scales a. The τ value provides the exact location of the wavelet; and a is the scale dilation parameter controlling the stretching (a >1) or contracting (0 < a <1) the wavelet. In the following, the Morlet wavelet is used: $\psi(t) = \pi^{-1/4} e^{i\omega_0 t} e^{-t^2/2}$ where $\omega_0 = 6$ is the central frequency of the wavelet.

The wavelet cross-spectrum is a measure of the distribution of power of two signals. For two time series of x and y, it is (Grinsted et al., 2004):

$$C_{xy}(a,b) = S\left(C_x^*(a,b)C_y(a,b)\right) \qquad (2)$$

where $C_x(a,b)$ and $C_y(a,b)$ represent the continuous wavelet transforms of x and y at scales a and positions b. The superscript $*$ denotes the complex conjugate and S is a smoothing operator in time and scale, which balances resolution and significance.

Coherence is one of the most commonly used technique for quantifying linear interactions, based on the Pearson correlation coefficient extended to time and frequency domains. The wavelet coherence (WTC) is a measure of the correlation between two time series, x and y, and defined as the squared absolute value of normalizing the wavelet cross-spectrum to the product of the single wavelet power spectrum of $C_x(a,b)$ and $C_y(a,b)$ (Grinsted et al., 2004):

$$R_{xy}^2(a,b) = \frac{\left|S\left(C_x^*(a,b)C_y(a,b)\right)\right|^2}{S(|C_x(a,b)|^2)\cdot S\left(\left|C_y(a,b)\right|^2\right)} \qquad (3)$$

where $0 \leq R_{xy}^2(a,b) \leq 1$ indicates the correlation degree between x and y. A value close to 0 (1 resp.) indicates a weak (strong resp.) relationship. That allows to depict the variability of correlation between the series in the time-frequency domain.

Results

For the purpose of consistency, only the results obtained from velocity logs related to wells W1 and W2 are presented (Fig.1).

The wavelet coherence spectra computed from the velocity logs related to the wells W1 and W2 are shown in Figure 2. They present the spatial variation of coherence in the domains depth-scale. A stronger correlation or dependency is demonstrated in yellow whereas the weaker correlation is marked in blue. The analysis of the obtained shows that reservoir depth intervals showing the presence of hydrocarbons, highlighted by dashed circles, correspond to the lowest coherence values at large scales. The weak correlation between the investigated velocity logs in presence of hydrocarbons is explained by the fact that contrary to P-wave, the propagation of S-wave is very affected in media containing fluids. Coherence may be suitably used to inspect the presence of hydrocarbons from velocity logs. These preliminary findings are very encouraging, and need to be confirmed using large datasets.

Conclusions

The scalograms of the wavelet coherence, obtained from velocity logs measured in Algerian wells, display the spatial correlation between Vp and Vs logs in the depth-scale domains. An important finding is the weak coherence values at large scales for reservoir depth intervals containing hydrocarbons. The wavelet coherence-based analysis would be of great help for identifying the presence of hydrocarbons from velocity well logs.

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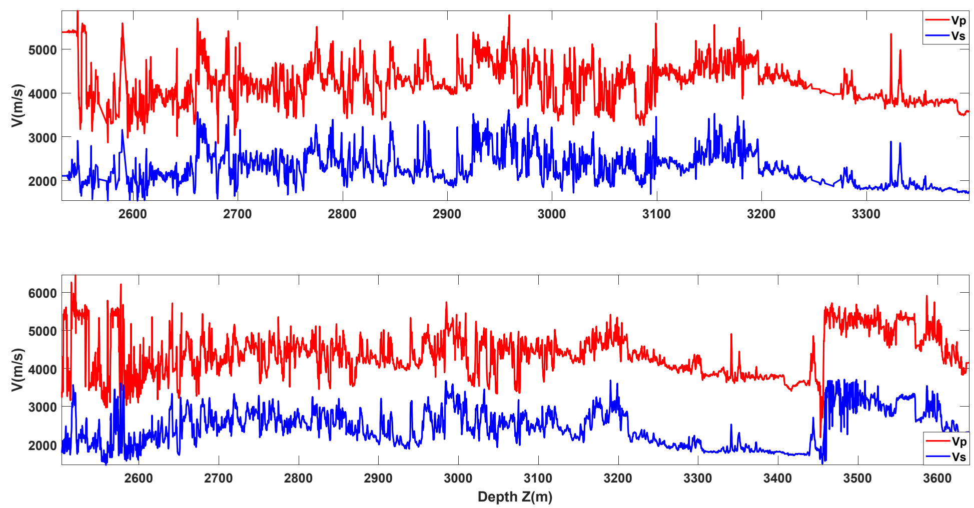

Figure 1. Analyzed velocity logs (Vp and Vs) recorded in well W1 (top panel) and well W2 (bottom panel) (in red: Vp log, and in blue: Vs log).

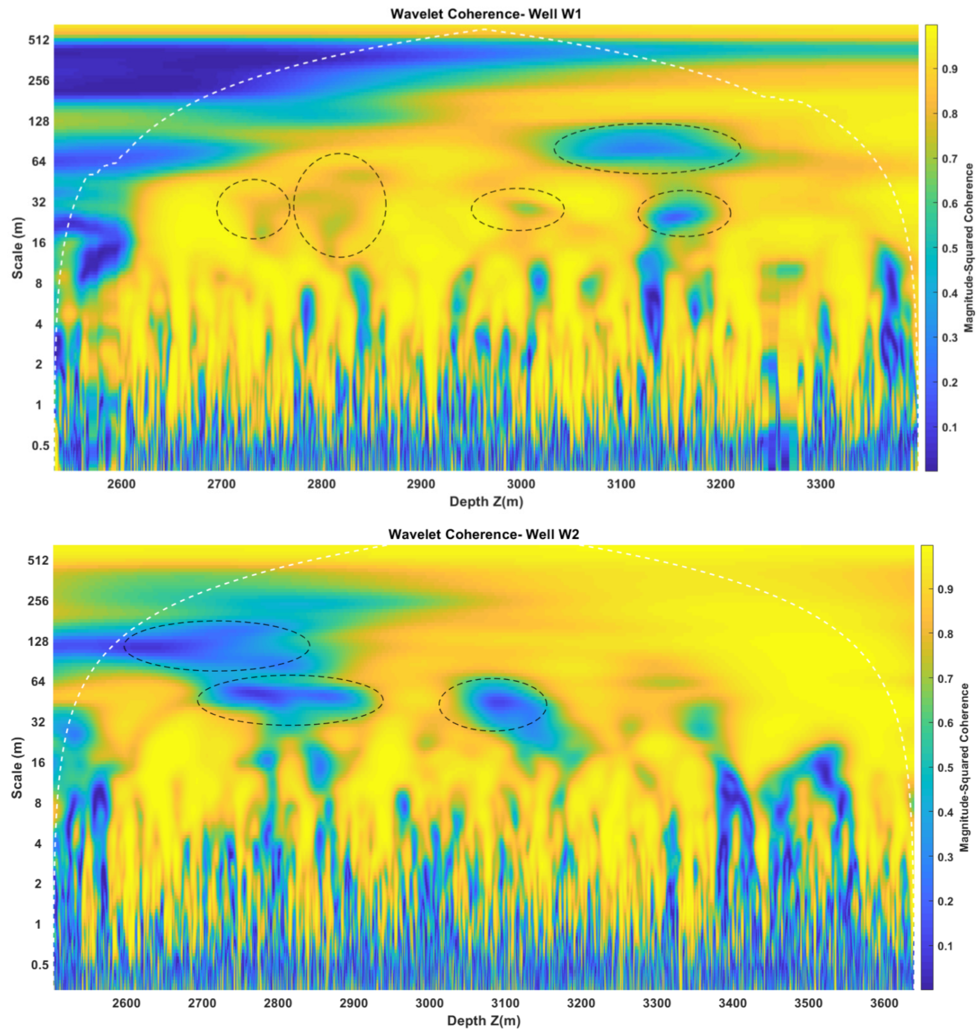

Figure 2. Wavelet coherence spectra between velocity logs (Vp and Vs) recorded in well W1 (top panel) and well W2 (bottom panel).The white dashed line is the cone of influence beyond which the energy is contaminated by the effect of zero padding. Dashed circles correspond to reservoir depth interval showing the presence of hydrocarbons