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Introducing the attribute of centroid of scale in wavelet domain and its application for seismic exploration

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Summary

This paper derives a scalogram formula of seismic wave in wavelet domain from the wavelet theory and the propagating equation of seismic wave in an anelastic medium. From the scalogram formula present a method for estimating seismic attenuation based on time-scale map and define the centroid of scale for characterizing attenuation as a new seismic attribute. A relationship between quality factor of propagation medium and centroid of scale is derived. Usually absorption related anomalies on seismic data are very important and usually are attributed to the presence of hydrocarbon reservoir and/or fault zones. Its expect that the deriving the behavior of attribute of centroid of scale can detect directory hydrocarbon reservoir or the fault zones. In this study all required computer codes are written in MATLAB environment. To evaluate the efficiency of the introduced seismic attribute in locating attenuation related anomalies, we applied the method on both real and synthetic seismic data. It is found that the low cost run time and high resolution are advantages of the method to others.

Methodology

Continuous wavelet transform

Continuous wavelet transform of a real signal x(t) with respect to an analytical wavelet ψ(t) is definedby the integral(Mallat,1999)

$$CTW_x(\tau,a)=<x,\psi_{\tau,a}>=\int_{-\infty}^{+\infty}x(t)\frac{1}{\sqrt{a}}\psi^*\left(\frac{t-\tau}{a}\right)dt \quad (1)$$

Where the window function ψ (t) is called the kernel wavelet. The overlain symbol " * " denotes the complex conjugate . The parameters a and τ called scale transtation,respectively. CWT , τ is called as wavelet transform coefficient. . $\hat{\psi}$(w) is the fourier transform of ψ (t).any function to be used as the kernel waveletshould be absolutely integrable and square integrable.it needs to meet the following admissibility condition.

$$c_\psi = \int_{-\infty}^{+\infty}\frac{\left|\hat{\psi}(w)\right|^2}{w}dw < \infty \qquad (2)$$

there are various wavelets that meet the above admissibility condition. A special wavelet might be selected according to real applications. one of this kind of wavelet is the analytical morlet wavelet

$$\psi(t) = \pi^{\frac{-1}{4}}e^{imt}e^{-\frac{t^2}{2}} \qquad (3)$$

where $5 \geq m$. One may modify the morlet wavelet to obtain the modified mrlet wavelet (Gao et al.,1998)

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$$\psi_m(t) = \pi^{\frac{-1}{4}} e^{imt} e^{-\frac{(ct)^2}{2}} \qquad (4)$$

where m is the modulating frequency, c is the modulating amplitude factor that controls the length of the wavelet function.

The representation of the continuous wavelet transform in frequency domain is

$$\hat{\psi}(w) = \sqrt{2}\pi^{\frac{1}{4}} c^{-1} e^{-(w-m)^2/2c^2} \qquad (5)$$

Deriving the relationship between quality factor and centroid of scale

A plane wave X(w,z) in theanlastic medium Is assumed with the quality factor is independent of the frequency. Its propagating equation(Aki et al., 1980) is defined

$$X(w,z) = X(w,0) e^{\frac{iwz}{c(w)}} e^{\frac{-wz}{2Qc(w)}} \qquad (6)$$

where w is angular frequency, z is propagating distance , X(w,0) is the source wave field at z=0 and c(w) is phase velocity . assuming that the source wavelet is an ideal impulse $(|X(w,0)| = 1)$, and omitting the attenuation caused by the velocity dispersion, applying the modified morlet wavelet (Equation 5), performing a continuous wavelet transform to Equation 6 and to obtain the seismic scalogram $|CWT_{a,b}(t)|^2$ that called energy density, (Mallat,1999)

$$|CWT_{a,b}(t)|^2 = \frac{a^{-1}}{\sqrt{\pi}} e^{-\frac{mt}{Qa} + \frac{c^2t^2}{4Q^2a^2} - \frac{c^2(t-b)^2}{a^2}} \qquad (7)$$

similar to the definition of measures of frequency based on the spectrogram(Barenes,1993), the definition of measures of scale based on the scalogram is given here. The centroid of scale as seismic attribute of a scalogram is defined

$$S_c(t) = \frac{\int_0^\infty |CWT(t,a)|^2 \frac{da}{a}}{\int_0^\infty \frac{1}{a} |CWT(t,a)|^2 \frac{da}{a}} \qquad (8)$$

from Equation 7,8, the centroid of scale can be yielded as

$$S_c(t) = \frac{mt}{Q}$$

so that the centtoid of scale is also invesrsely proportional to the quality factor. The large centroid of scale implied the low quality factor and the signal attenuates seriously.

There for The attenuation of anomalies can be characterized by the sumation large scales of centroid.

Synthetic seismic data application

a simple three –layer geological model is assumed according with under table.

properties	Velocity M/S	Density Kg/m3	Quality factor
Layer-1	٢٠٠٠	٢٢٥٠	٤٠٠
Layer-2	٢٣٠٠	٢٢٥٠	١٥٠
Layer-3	٢٤٥٠	٢٢٥٠	٥٠
Layer-4	٢٦٠٠	٢٢٥٠	٥٠

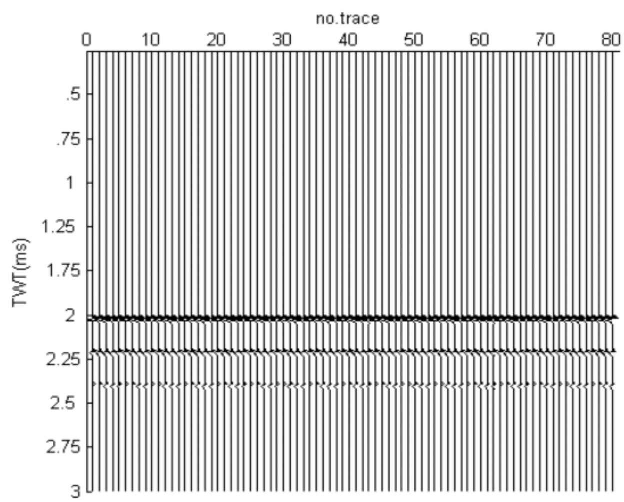

Figure1-seismogram of three-layer geological model

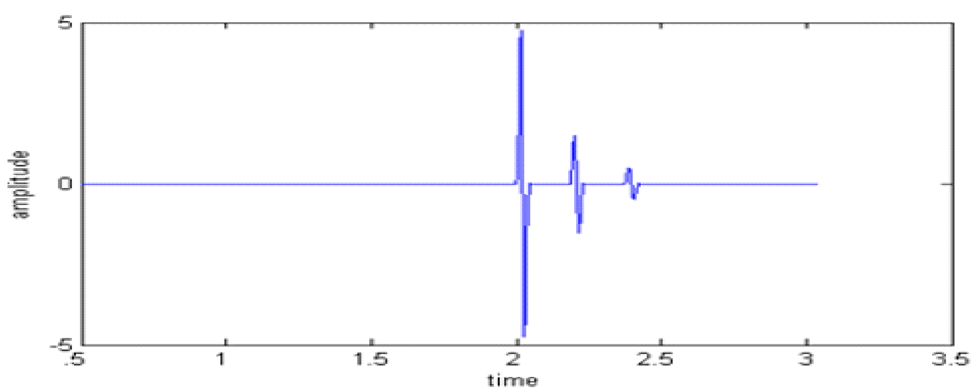

Figure 2- sample of seismogram figure1

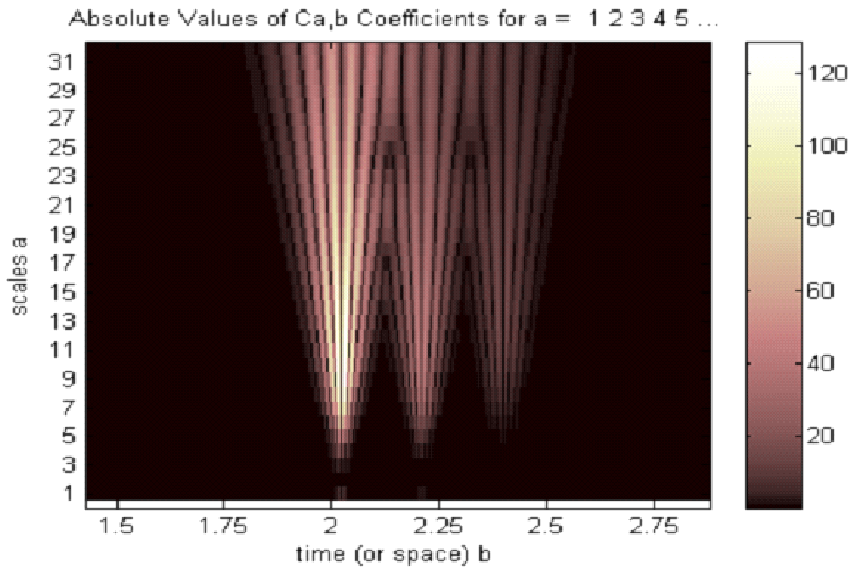

Figure3- scale-time map(scalogram) of continuous wavelet transorm figure2

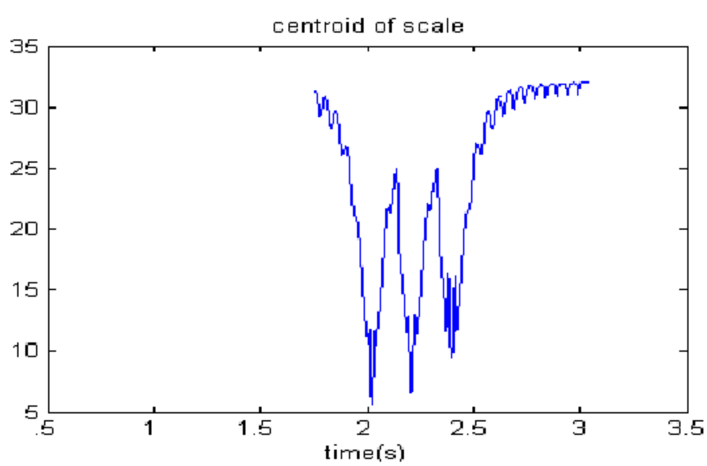

Figure4- centroid of scale of scalogram figure3 as attenuation attribute.

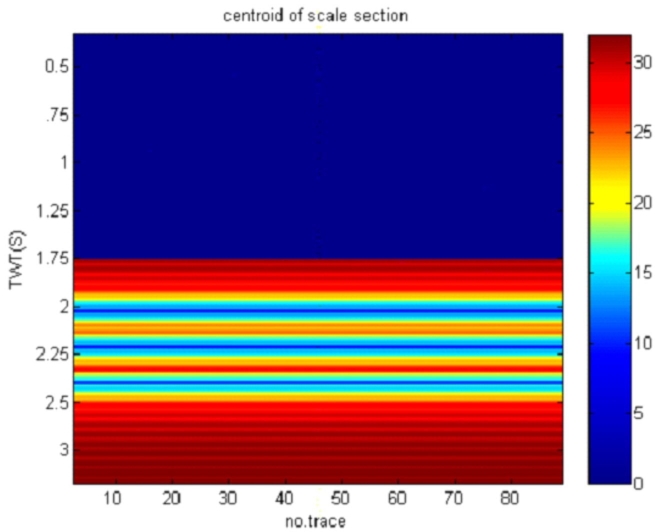

Figure6- section of centroid of scale is applied from continuous wavelet transorm seismic section figure1

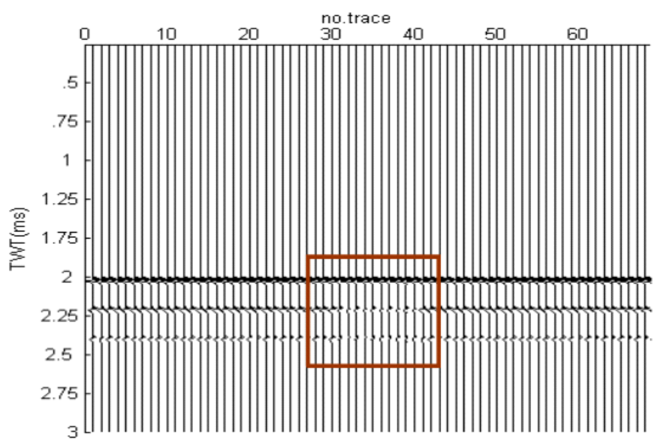

Figure7- seismic section of a three –layer model with an anomaly between no-CDP 30 and no-CDP40 with Q=10

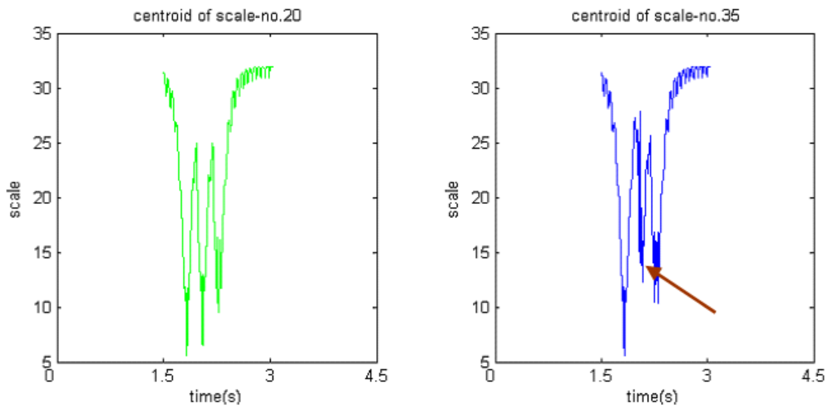

figure8-the left is centroid of scale is calculated from no-trace20 and the right is centroid of scale of no-trace35

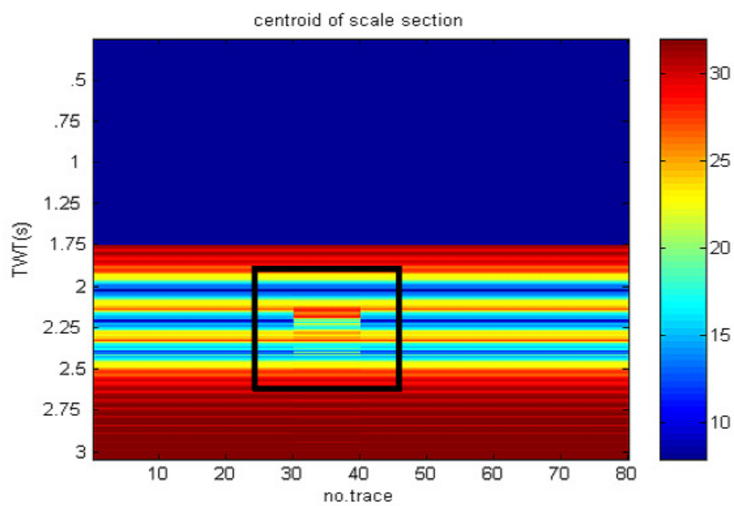

Figure9- centroid of scale section is applied from seismic section figure7.in this section **anomaly is *characterize d***

Real seismic data application

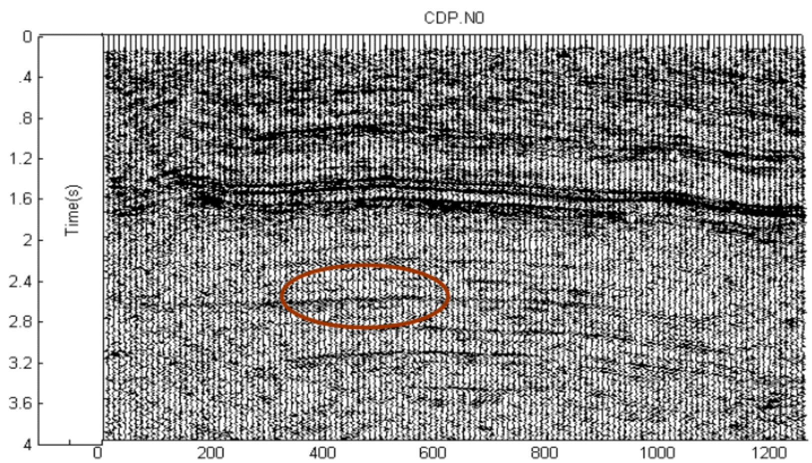

Figure10-seismic stacked section that gas reservoir is reported at CDP.no=500 and time=2.5s

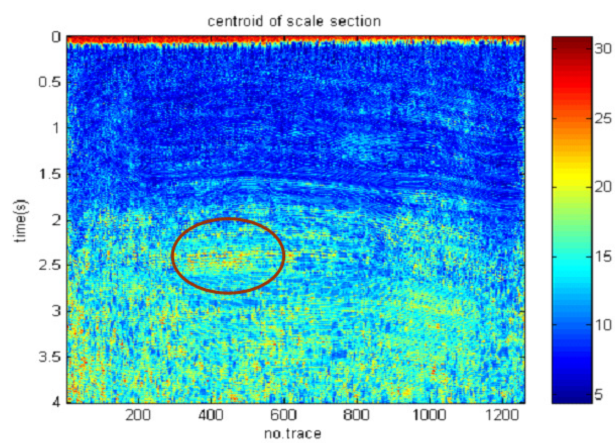

Figure11- The extracted centroid of scale section of Figure 10. In this figure anomaly of gas reservoir is estimated in around no-CDP=500 and time=2.5