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Hydrocarbon detection using adaptively selected spectrum attenuation

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ABSTRACT

Hydrocarbon reservoir usually shows the characteristics of low frequency amplifying and high frequency attenuating, which has been used as hydrocarbon indicator. However, reflection interference may also cause these phenomenons. In this paper, we propose an adaptively selected spectrum attenuation method to reduce the impact of the reflection interference in hydrocarbon detection. We first evaluate spectrum attenuation of seismic data by calculating the ratio of high frequency to low frequency components for each trace in the time-frequency domain. Notice that high frequency components are not really attenuated by interference as they appear, they can be recovered later, so we use an edge-preserving smoothing (EPS) method to smooth the equivalent local peak frequencies (ELPFs) located at the local peaks of seismic envelope to measure the attenuation trend of a seismic trace, and choose the spectrum attenuation whose high frequency components are really attenuated to locate the hydrocarbon. A real seismic data example demonstrates that the spectrum attenuation calculated by the ratio can avoid the impact of strong reflection, and the selected spectrum attenuation can reduce the effect of interference, which makes it more reliable in locating hydrocarbons than use the spectrum attenuation directly.

1. Introduction

Since the inception of bright spot technology in the 1960s, low-frequency shadows beneath amplitude anomalies have been used as a substantiating hydrocarbon indicator (HI). At the 1996 SEG/EAGE Summer Research Workshop, Dan Ebrom summarized at least 10 mechanisms that can explain these low-frequency shadows (Ebrom, 2004). Following that, Castagna et al. (2003) use instantaneous spectral analysis (ISA) based on Mallat's matching pursuit decomposition to directly detect hydrocarbons for gas reservoirs from high frequency attenuation anomalies, and/or low frequency shadows. Sa et al. (2004) and Hu et al. (2005) demonstrate that hydrocarbon reservoir shows low frequency resonating (LFR) and high frequency attenuating (HFA) through laboratory testing, numerical simulation and petrological analysis based on multi-phase theory and double-phase theory respectively. This discovery therefore further explains the low-frequency shadows and provides some new methods to directly detect oil and gas using seismic information (Hu et al., 2005, 2009; Sa et al., 2004). Chen and Gao (2007) proposed to detect hydrocarbons by using the difference between high and low frequency components based on their modified best matching seismic wavelets (MBMSW). Jiang et al. (2010) combined the high frequency attenuation gradient and low frequency energy information using MBMSW to detect hydrocarbon. Zhou et al. (2010) decomposed seismic data trace by trace into a set of Ricker wavelets with different dominant frequencies using wavelet transform (WT), and for each trace calculated the difference of two amplitude spectrums, one of which is computed by adding up the WT amplitude spectrums inside a window above the target layer under investigation and the other from a window below the target layer. The two amplitude spectrums are normalized before computing their difference. Then the locations with negative values at low frequency and positive values at high frequency may indicate being hydrocarbon-bearing (Zhou et al., 2010).

However, if the layers are thin enough, reflections at the boundaries will interfere with each other, and their superposition may produce a 'fat' compound waveform which has much lower dominant frequency. As a result, the high frequency components appear to be attenuated and the low frequency components may be increased for the seismic trace at the time window, which will mislead us in hydrocarbon detection. In reality, when the layers are thick enough at a later time, no

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interference will present, the reflected waves as well as these frequency components will recover. Taking advantage of this, we propose an adaptively selected spectrum attenuation method to reduce the impact of interference in hydrocarbon detection. We first transform seismic data into time–frequency domain using Short-Time Fourier Transform (STFT) trace by trace, then derive spectrum attenuation for each trace by calculating the ratio of high frequency to low frequency component. Then we use an edge-preserving smoothing (EPS) method to smooth the equivalent local peak frequencies (ELPFs) located at the local peaks of seismic envelope to find the attenuation trend of the high frequency components. Finally, hydrocarbons are detected by choosing the spectrum attenuation whose high frequency components are really attenuated.

2. Theory

2.1. Short-Time Fourier Transform

Following Mallat (2003), we introduce windowed Fourier atom which is constructed by a real and symmetric window $g(t) = g(-t)$ translated by u in time and by ξ in frequency:

$$g_{u,\xi}(t) = g(t-u)\exp(i\xi t). \tag{1}$$

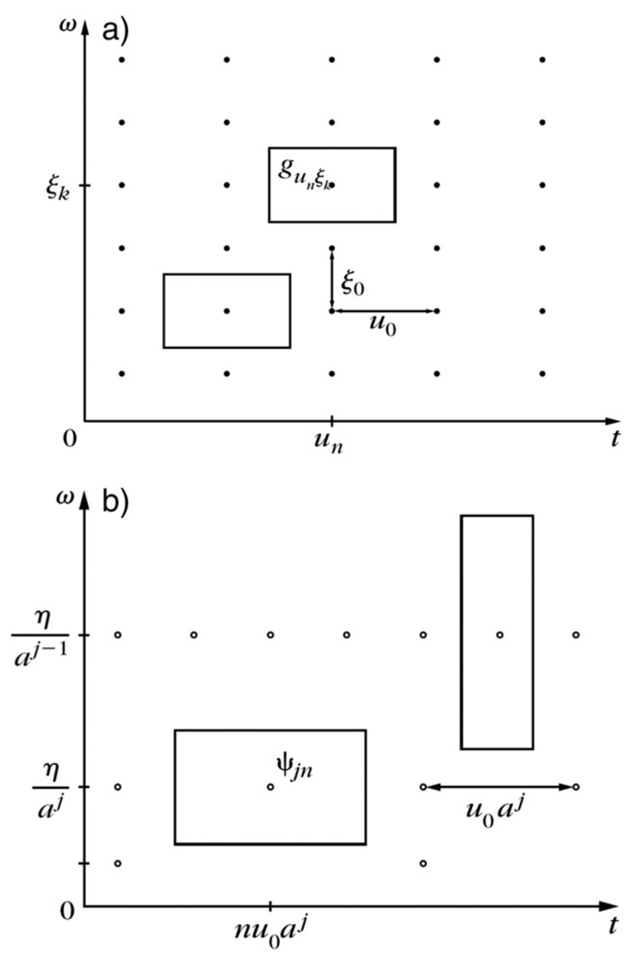

Fig. 1. Heisenberg time–frequency boxes of (a) Short-Time Fourier frame covering the time–frequency plane with a regular grid of Short-Time Fourier atoms, translated by $u_n = nu_0$ in time and by $\xi_k = k\xi_0$ in frequency, and (b) wavelet frame scaled by $s = a^j$ has a time and frequency width proportional to a^j and a^{-j} respectively. Mallat (2003).

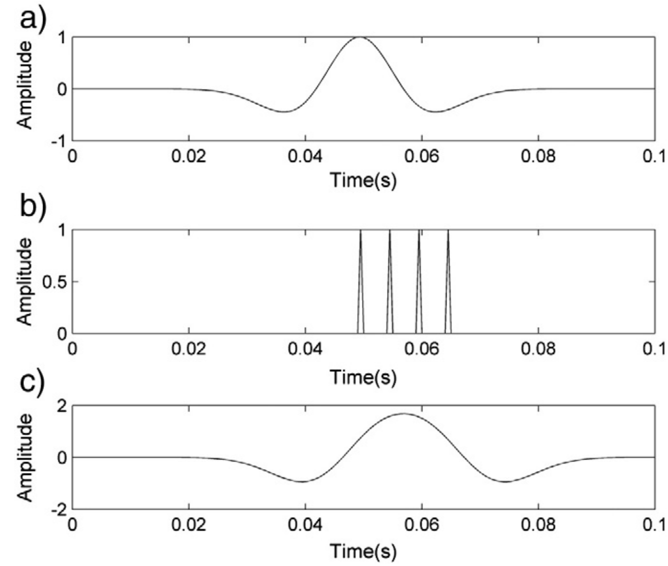

Fig. 2. Thin bed model example. (a) 30 Hz Ricker wavelet; (b) thin bed model with four reflectivity coefficients which have the same magnitude and sign; (c) synthetic seismic trace generated by convolving (a) with (b).

It is normalized such that $||g|| = 1$, thus $||g_{u,\xi}|| = 1$ for any $(u, \xi) \in R^2$. The resulting Short-Time Fourier Transform (STFT) of $s \in L^2(R)$ is

$$S(u,\xi) = \left\langle s, g_{u,\xi} \right\rangle = \int_{-\infty}^{\infty} s(t) g(t-u)\exp(-i\xi t)dt \tag{2}$$

where u is the location of the window center, $\xi = 2\pi f$, the multiplication by $g(t-u)$ localizes the Fourier integral in the neighborhood of $t = u$.

If we discrete the time and frequency parameters (u, ξ) over a rectangular grid with time and frequency intervals of size u_0 and ξ_0, we can get the Short-Time Fourier frame $g_{n,k}(t) = g(t - nu_0)\exp(ik\xi_0 t)$, and the corresponding Heisenberg boxes representing the energy spread of Short-Time Fourier frame (Mallat, 2003) are illustrated in Fig. 1a. From this figure, we can see that the frequency of STFT is regular, so the low frequency and high frequency components are comparable. And if ξ_0 is sufficiently small, the frequency will be densely sampled, which will be more accurate for measuring the attenuation trend.

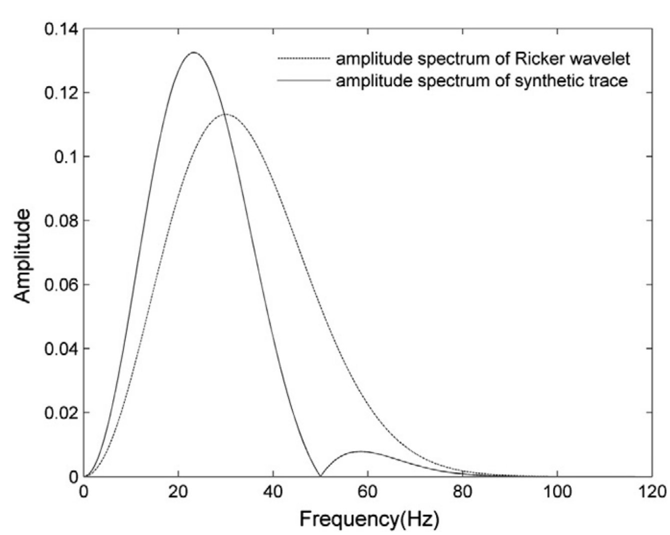

Fig. 3. Energy normalized amplitude spectrum of the 30 Hz Ricker wavelet in Fig. 2a (dotted line) and the synthetic seismic trace in Fig. 2c (solid line).