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Effect of Attenuation on Thin Sand Bed AVO

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Abstract
Thickness prediction of thin bed is one of most important research objectives of fine reservoirs characterizations in seismic exploration. AVO research on thin bed is one of its important applications. Usually, only primary reflections are produced in AVO modeling by the convolution method, in addition, no attenuation is considered within such modeling. Modeling algorithm based on reflectivity method can simulate the whole responses to thin bed, and consequently the modeling results are closer to real seismic waves. Reflectivity method was used to model

AVO for two types of thin beds, which are with and without attenuation. After comprehensive analysis of AVO attributes, we summarized some rules about AVO attributes with the thickness of thin bed. These characteristics and rules are helpful for us to predict the thickness of thin bed in practice.
Keyword: THIN BED, AVO, ATTENUATION, REFLECTIVITY METHOD, RICKER WAVELET

1. Introduction

With the development of seismic exploration for oil and gas, thin bed reservoirs are becoming one of the important targets in oil industrial. In thin beds, seismic reflections from different interfaces interfere each other to be composite wave, therefore, it is different to identify and describe the range and the thickness of thin sand using the conventional method. Currently, the methods, such as, seismic amplitudes [1-3], spectrum analysis [4-6], comprehensive seismic attributes and seismic inversion [7, 8], are used to predict the thin beds. AVO is an important seismic exploration technique, which has been applied to the research on thin beds. Many works have been done by a lot of researchers [9-14]. Sun, et al [15] showed that there are not only the positive AVO anomaly but also the negative AVO anomaly and the non-positive/non-negative anomaly of gas reflection after the analysis of the real reflection of thin inter-bed sand and shale. Lin, et al [16] established the relation between AVO intercept/gradient of thin bed and AVO intercept/gradient of single interface. Zhao, et al [17] made a series of thin inter-bed models and analyzed the AVO amplitudes of thin sand-shale of different thickness to discuss the relation of AVO and the bed thickness. Cai, et al [18] talked about the effect of different frequency of wavelet on AVO amplitude and spectrum and the relation between AVO amplitude and the thin bed thickness. Li, et al [19] analyzed the seismic attributes of thin inter-bed and the reflection and instantaneous frequency that behave like a single sand.

Most of research above are based on convolution model, consequently, there is only the primary in the simulating result without the multiples and the converted waves. Moreover, the bed attenuation is not considered for AVO, so the results of these researched are limited and insufficient in practice. Therefore, further works are needed to study and discuss the effect of the thin bed tuning and the attenuation on the AVO attributes, and to find the AVO attributes sensitive to the thickness of the thin bed. In this paper, the reflectivity method [20, 21] is taken to simulate the AVO response of a single thin bed with and without attenuation, after the comprehensive analysis of the different AVO attributes, some rules are drawn about the AVO responses of a single thin bed with and without attenuation, which are a reference and a guide to predict the thin bed.

2. The Thin Tight Sand Model

2.1. Model Design and Elastic Parameters

Based on the characteristics of thin reservoir in a gas basin of China, we established a single thin bed model of tight sand, which is shown in Table 1. The model has three layers: the middle layer is tight sand, top one and bottom one are shale. In table 1, Vp is the P wave velocity, Vs is the S wave velocity, Qp is the quality factor of P wave, Qs is the quality factor of S wave. For the sand layer, its thickness varies by the wavelength λ of seismic wavelet. The minimum of sand thickness is $\lambda/32$, the maximum of sand thickness is $8\lambda/32$, the increment is $\lambda/32$.

Table1. The elastic parameters of model

Lithology	Thickness (m)	Density (g/cm^3)	Vp (m/s)	Vs (m/s)	Qp	Qs
Shale	1000	2.4	3900	2100	500	500
Sand	λ/n	2.5	4200	2500	500/50	500/50
Shale	1000	2.4	3900	2100	500	500

2.2. The AVO Modeling of Thin Bed

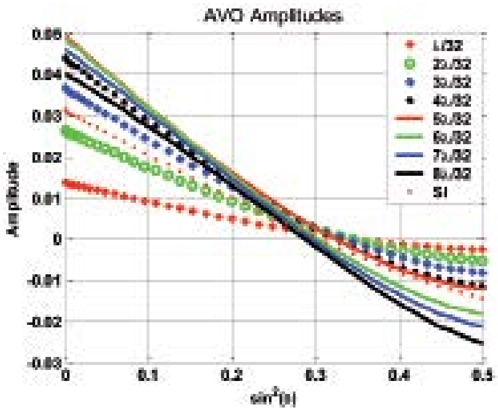
Some researches [1, 22] show that the result may be wrong if there are no consideration of the multiples and the converted wave in modeling of the thin bed. For producing the AVO responses of thin sand bed which are most close to real seismic response, the reflectivity method is taken to simulate the seismic response of the models with different thickness in Table 1. In modeling, the seismic wavelet is the Ricker wavelet with peak frequency of 30 Hz. The range of offset is from 0m to 2500m, the offset increment is 50m. For the comparison with the single interface, the AVO responses are also modeled for the single interface composed with shale and sand. In the case of no attenuation, we set the quality factor to 500 for both P wave and S wave; In the case of attenuation, we set the quality factor to 50 for P wave and S wave. After simulating, the AVO gathers are used for the subsequent analysis.

3. AVO Attributes Analysis

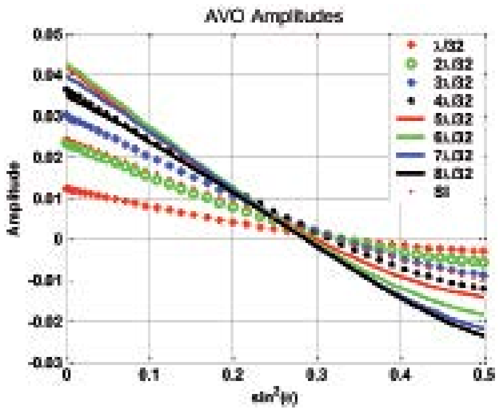
3.1. AVO Amplitudes and Intercept/Gradient

These AVO gather in offset domain are converted into angle domain and the amplitude at first peak are picked to get the AVO curves with incident angle of different thin thickness. In Figure 1, the horizontal coordinate is $\sin^2\theta$, θ is the incident angle. In legend, the thickness of thin bed is expressed by wavelength. SI indicates the single interface. From the figure, it can be seen that the reflection amplitudes are positive at the top of sand, and the amplitudes decrease with offset for the two models. At about incidence angle 35°, the reflection amplitudes are closely zero; after that, the reflection amplitudes remain to decrease, however, its absolute values increase. There are apparent differences between AVO amplitudes of thin bed with different thickness. The whole characteristics of AVO amplitudes are similar for the model with/without attenuation. However, the effect of attenuation on AVO amplitudes are obvious because it make the amplitudes smaller. So, the attenuation should be considered in AVO amplitude analysis.

AVO intercept/gradient as show in Figure 2 are calculated from AVO amplitudes in Figure 1. Obviously, AVO intercepts are positive and AVO gradients are negative. For sand with different thickness, the AVO intercept/gradient are in a linear distribution, and they differ each other except for the thickness $7\lambda/32$ and $8\lambda/32$, which are good indicator and can be used for distinguishing the different thickness. AVO intercept/gradient in Figure 2 has more reso-

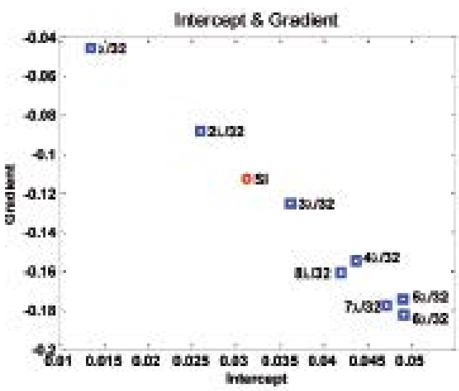


a. the model without attenuation

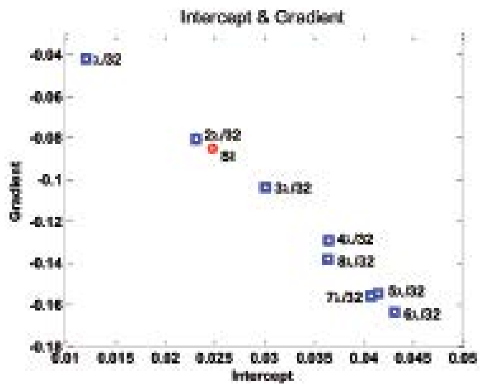


b. the mode with attenuation

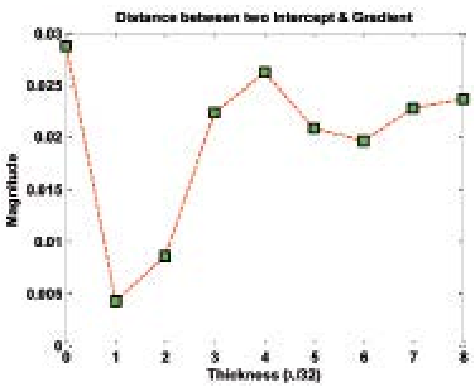
Figure 1. AVO amplitudes



a. model without attenuation



b. model with attenuation



c. intercept/gradient space distance

Figure 2. AVO intercept/gradient

lution than AVO amplitudes in Figure 1. Under the influence of attenuation, AVO intercept/gradient in Figure 2b are a bit of difference from that in Figure 2a. For displaying the effect of attenuation on AVO intercept/gradient clearly, space distances are defined as L2 norm of AVO intercept/gradient and calculated for AVO intercept/gradient in Figure 2a and Figure 2b. The space distances of AVO intercept/gradient are displayed in Figure 2c. The first point in Figure 2c is the single interface. From Figure 2c, the effect of attenuation on AVO intercept/gradient increase with the thickness of thin bed and reach the maximum at the thickness $4\lambda/32$, then the changes are mall. This means the effect of attenuation on AVO intercept/gradient varies for the different thicknesses, consequently, the attenuation is a factor that can not be ignored in AVO analysis.

3.2. AVO Spectrum of Thin Bed

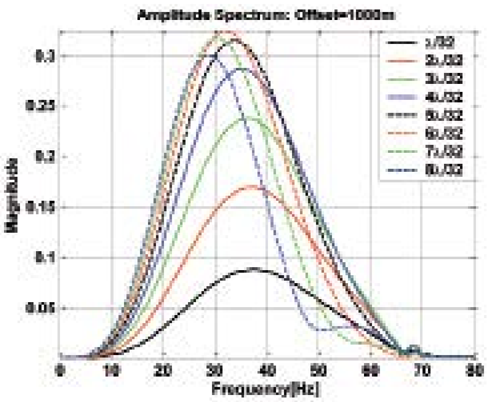
Next, we will analyze the characteristics of the amplitude spectrum changing with offset. Figure 3 displays the amplitude spectrum of different thickness. Figure 3a-3d show the amplitude spectrum of offset 1000m and 2000m. For the model with/without attenuation, the amplitude spectrum increase with the thickness of thin bed except for thickness $7\lambda/32$ and $8\lambda/32$ on offset 1000m. For 2000m offset, there are clear differences among the amplitude spectrum for all the thicknesses. For the model with attenuation, the magnitude of the spectrum are lower than that of the model without attenuation, although the trends are basically consistent. So, the effect of attenuation on AVO spectrum are perceptible.

3.3. AVO peak attributes

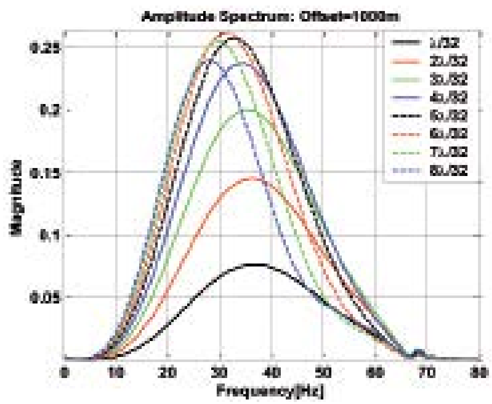
Next, AVO peak attributes are calculated, such as peak amplitude, peak frequency and the ratio of peak frequency to peak amplitude, as shown in Figure 4.

Figure 4a and Figure 4b show the peak amplitude. For the model with/without attenuation, the peak amplitude increase firstly and then decrease at near offset (0m, 500m and 1000m). The peak amplitude increase linearly with the thickness of thin bed at mid and far offset (1500m, 2000m and 2500m). For the model with attenuation, the magnitudes are smaller than that of the model without attenuation.

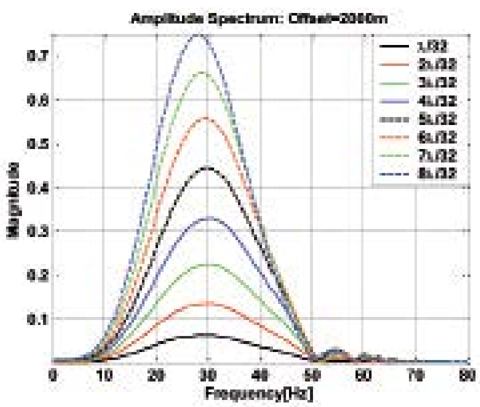
Figure 4c and Figure 4d show the peak frequency. For the model with/without attenuation, the peak frequency decrease with the thickness of thin bed at near and mid offset (0m, 500m, 1000m and 1500m). The peak frequencies vary slightly at far offset (2000m



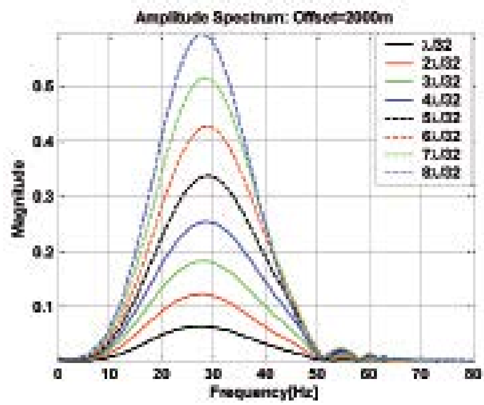
a. 1000m offset (the models without attenuation)



b. 1000m offset (the models with attenuation)



c. 2000m offset (the models without attenuation)

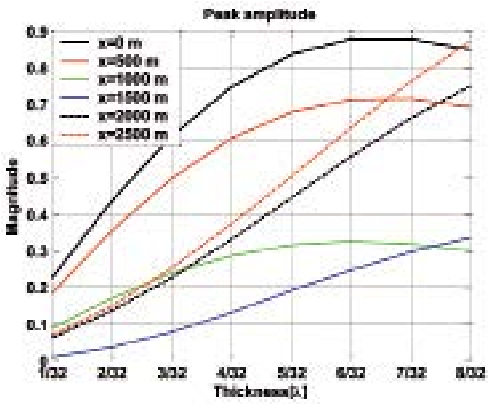


d. 2000m offset (the models with attenuation)

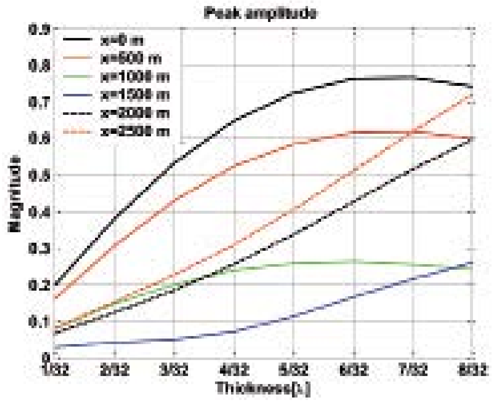
Figure 3. Amplitude spectrum

and 2500m). Influenced by attenuation, the peak frequency of the model with attenuation are lower. Even, for the 1500m offset in model with attenuation, the peak frequency is different from other offsets, so it is abnormal than can not be used in the subsequent analysis.

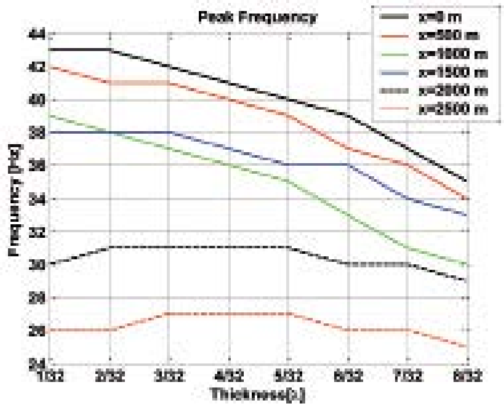
Figure 4e and Figure 4f show the ratio of peak frequency to peak amplitude. For the model with/without attenuation, the thinner the thickness is, the bigger the ratio of peak frequency to peak amplitude is. However, for the model with attenuation, the magnitude are bigger than that of the model without attenuation for the thinner thickness at near offsets (0m, 500m and 1000m), which is better to identify the thickness of thin bed. In practice and in the case of attenuation, the data of near offset are in higher S/N ratio and are available to analysis. In a whole, the ratio of peak frequency is a good attribute and is especially better for predict the thinner thickness.



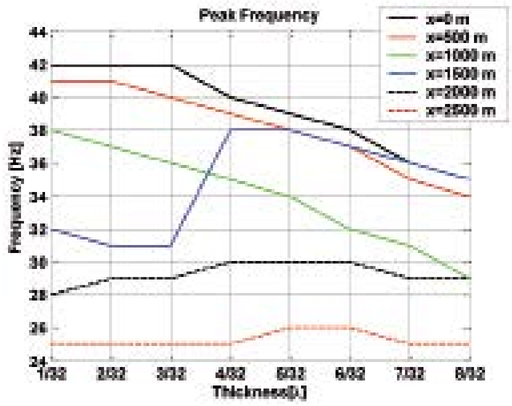
a. the peak amplitude (the models without attenuation)



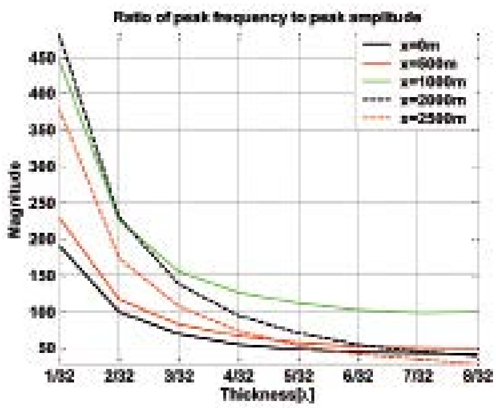
b. the peak amplitude (the models with attenuation)



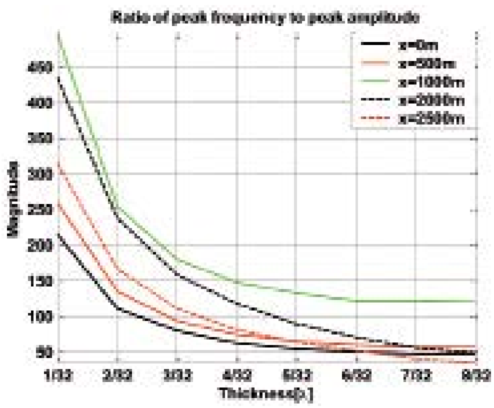
c. the peak frequency (the models without attenuation)



d. the peak frequency(the models with attenuation)



e. the ratio of peak frequency to peak amplitude (the models without attenuation)



f. the ratio of peak frequency to peak amplitude (the models with attenuation)

Figure 4. AVO Peak Attributes

Conclusions

In this paper, the reflectivity method is taken to simulate the AVO responses of the model with/without attenuation, and the AVO attributes are analyzed with the thickness and the offset.

The reflection amplitudes on the top of thin sand bed are positive, and decrease with offset. The AVO intercept/gradient of different thickness of thin sand are in a linear distribution. AVO amplitude spectrums increase with the thickness of thin bed. The peak attributes change with the thickness of thin bed and the offset. These attributes can be used for prediction of thin sand bed.

The attenuations have effect on AVO amplitudes, AVO intercept/gradient and the peak attributes. So, the attenuation is perceptible and should be considered as an important factor in AVO analysis.

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