SEISMIC CHARACTERIZATION AND MONITORING OF THIN-LAYER RESERVOIR

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Thin-layer reservoir has great significance for oil exploration and development. Seismic characterization and monitoring of thin-layer reservoir has spatial advantage. New seismic attributes and attributes combination analysis are proposed, including attributes versus incidence angle, attributes versus scale, reflection coefficient spectrum and time-frequency analysis for detailed thin-layer reservoir characterization.

1 Introduction

Thin-layer reservoirs are large in north china and other areas in the world. It is also an important research topic for geophysicists. With the development of oil exploration, detailed analysis of thin-layer reservoir is needed.

Many researchers have done important work in this area. Widess studied amplitude character of thin-layer using normal pulse reflections[1]. Lange, Rafipour and Marfurt studied seismic attributes for thin-layer and fluid discrimination[2][3][4]. Christopher and James analyzed the effect of the converted wave and multiple on thin-bed and AVO modeling[5][6]. Chung analyzed the precision of different approximation[7]. Liu studied the amplitude attributes for thin-layer using acoustic wave equation modeling method[8]. Ellison studied the modeling and analysis method for thin-layer reservoir monitoring [9].

We studied new attributes and attributes combinations for thin-layer reservoir characterization and monitoring.

2 Thin-layer seismic modeling

Many author using convolution based modeling method in thin-layer studies[1][5]. Reflectivity method can also be used[6]. We use a method similar to that used by Liu[8], but our method is based on elastic equation. There is no analytical expression for these method. Detailed derivation is in appendix. Figure1 is the modeling result for a simple model with only three layers.

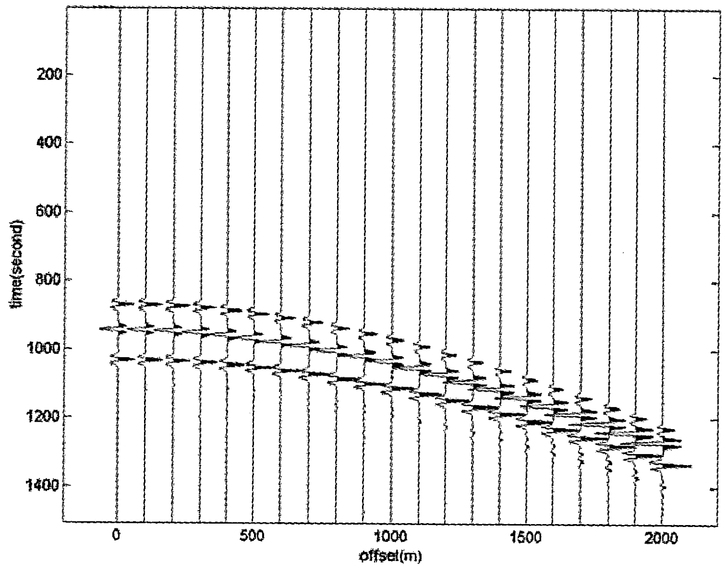


Figure1 Seismic modeling result for a simple model with three layers

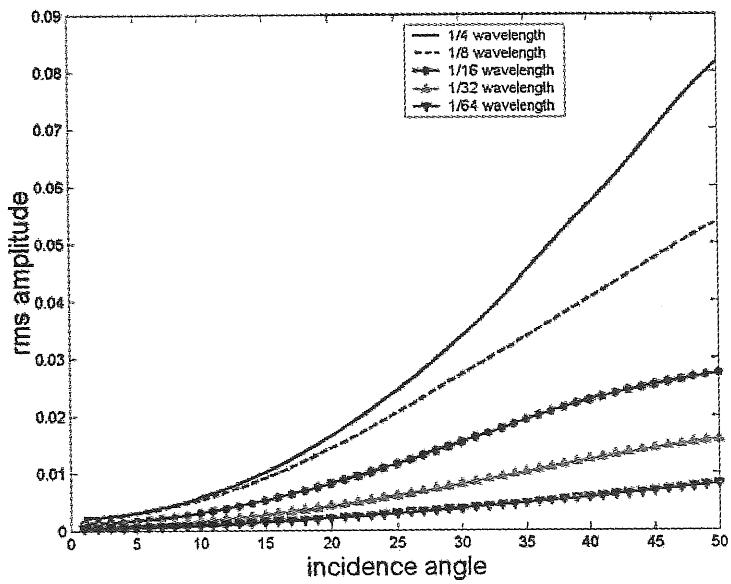
3 Seismic attributes versus incidence angle for thin-layer

AVO has been widely used in oil exploration. Mazzotti also proposed the combined amplitude, phase and frequency versus offset analysis for layered bed[10]. We use this method in thin-layer reservoir analysis.

Three layer model is studied. The upper and lower layer are both shale and the middle layer is sand. The rock properties for the model is in table1, which is excerpted from [11]. The thickness of the middle layer can be changed. Later experiment is also based on this data. Figure2-Figure5 is amplitude and phase versus incidence angle for the three models when bed thickness change. Conventional analysis used only amplitude. Our studies show that phase can help separate different thickness of the bed. Figure6 is amplitude and phase versus incidence angle for velocity change. There are good correlation between amplitude, phase versus incidence angle and velocity change.

Table1 rock properties used for the synthetic seismograms

	Vp(m/s)	Vs(m/s)	ρ (g/cc)	Sw
Shale	3900	2086	2.300	
Sand1	3855	2202	2.320	1
Sand2	3597	2217	2.288	0.8
Sand3	3755	2254	2.192	0.2



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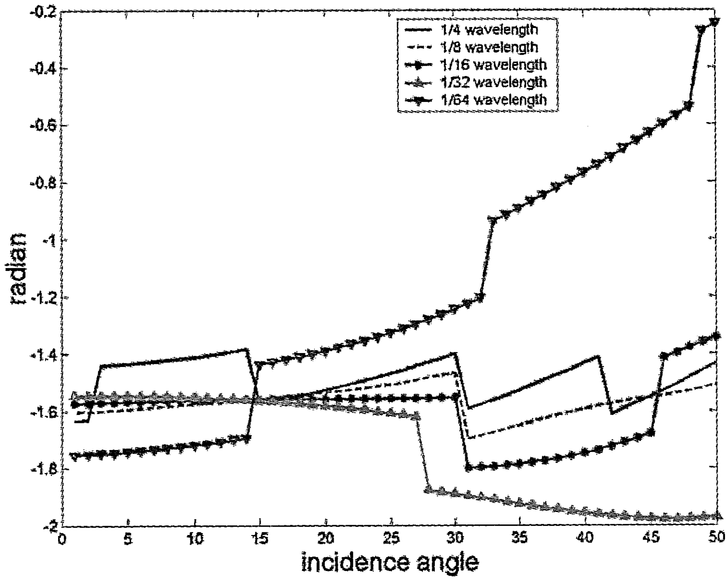

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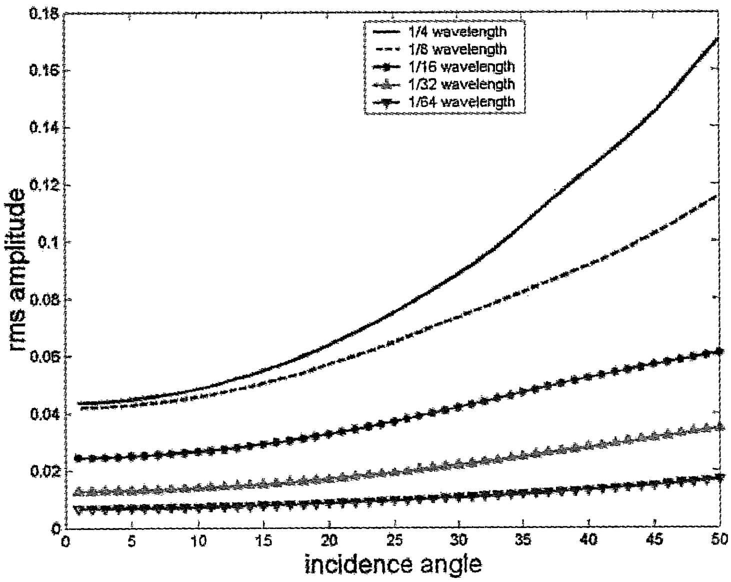
Figure 2 Amplitude versus incidence angle for different thickness (a) and phase versus incidence angle for different thickness (b) for saturation=1



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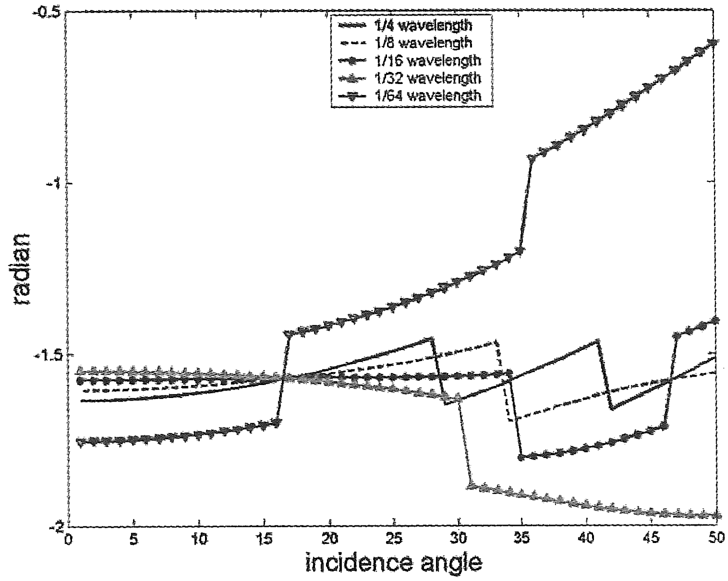

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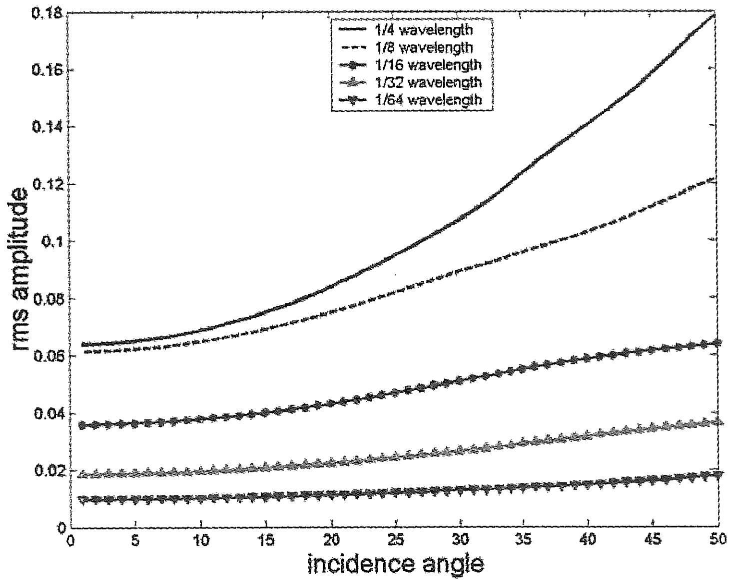
Figure 3 Amplitude versus incidence angle for different thickness (a) and phase versus incidence angle for different thickness (b) for saturation=0.8



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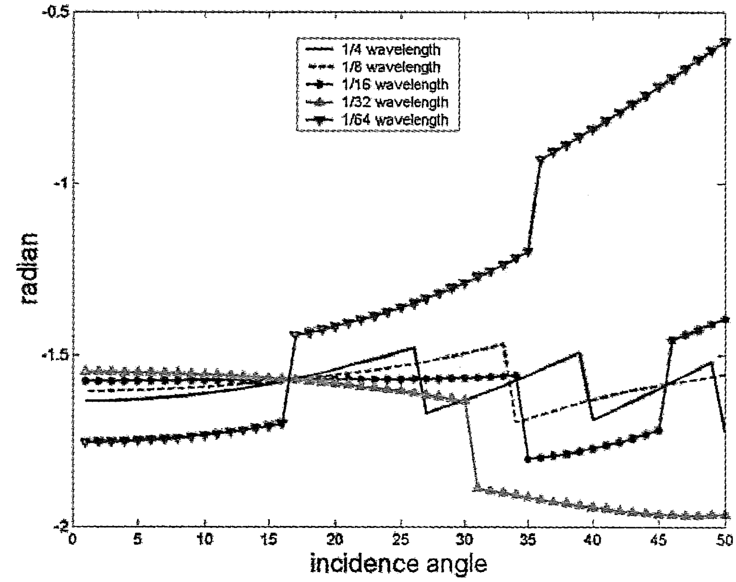

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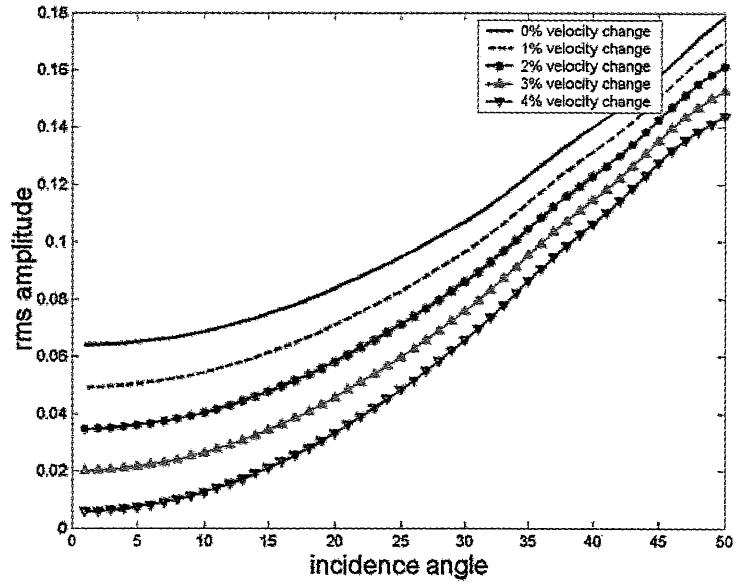
Figure 4 Amplitude versus incidence angle for different thickness (a) and phase versus incidence angle for different thickness (b) for saturation=0.2



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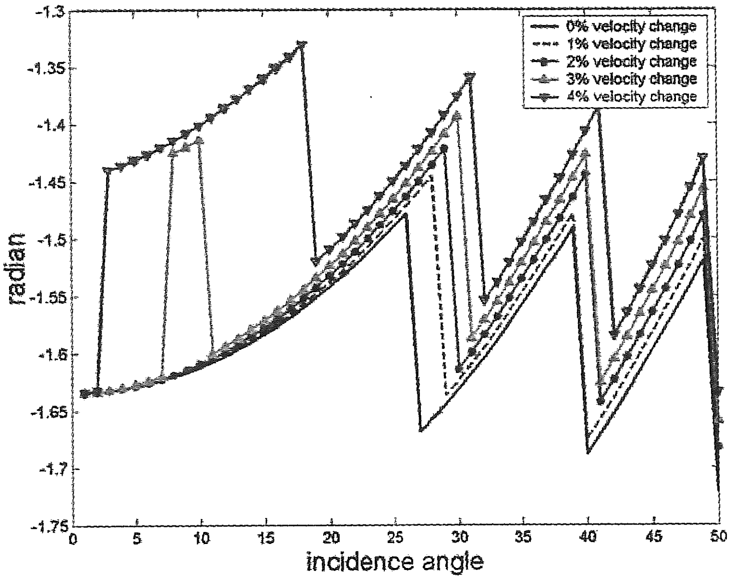

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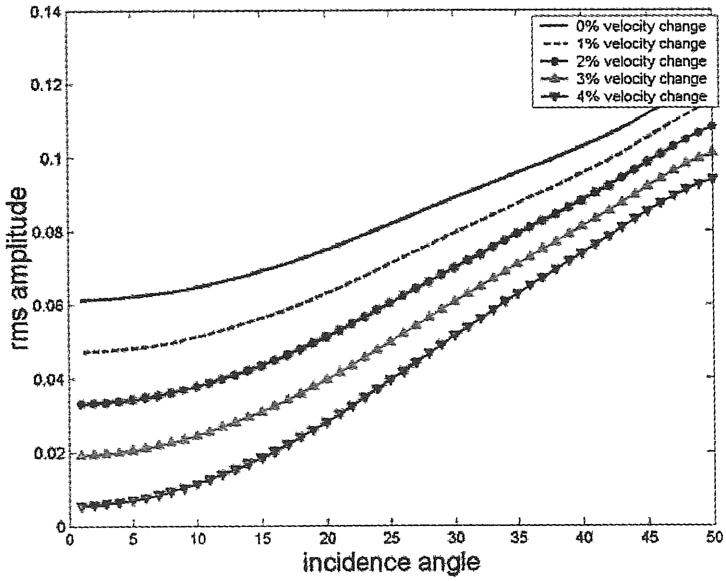
Figure 5 Amplitude versus incidence angle for different velocity change (a) and phase versus incidence angle for different velocity change (b) for saturation =1 and thickness=0.25 wavelength



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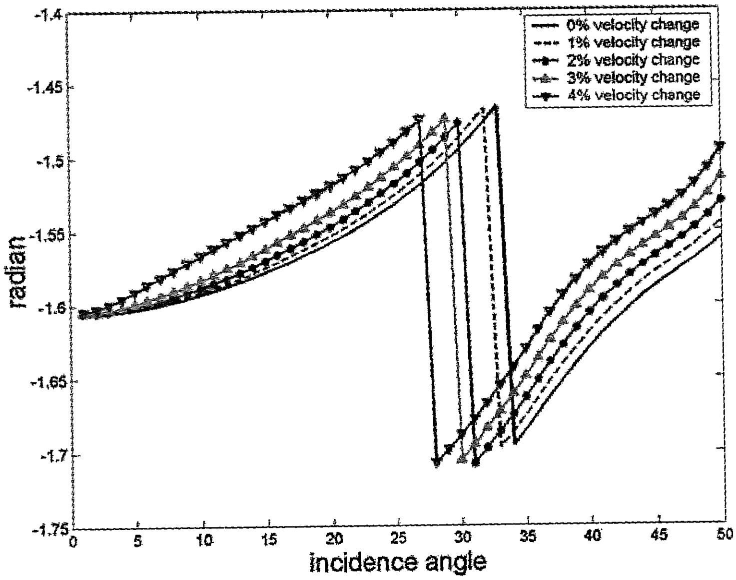


(b)

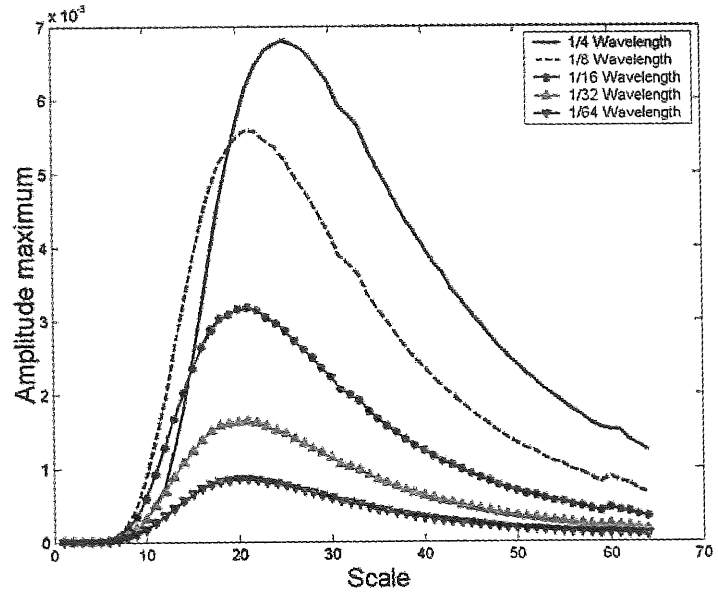
Figure 6 Amplitude versus incidence angle for different velocity change (a) and phase versus incidence angle for different velocity change (b) for saturation =1 and thickness=0.125wavelength

4 Seismic attributes versus scale for thin-layer

Wavelet transform is helpful in analyzing energy and frequency difference[12]. Seismic attributes versus scale is proposed and tested in thin-layer analysis.

The theory of wavelet is not discussed here. We use continuous wavelet transform and morlet wavelet is chosen.

Figure7 is amplitude versus scale for different bed thickness. Both amplitude maximum and corresponding scale are different for bed thickness change. So the new attributes can better delineate thin-layer bed thickness. Figure8 is amplitude versus scale for different incidence angle. When incidence angle increases, amplitude increases and scale decreases. Figure9 is amplitude versus scale for different velocity change. Velocity change mainly affects amplitude.



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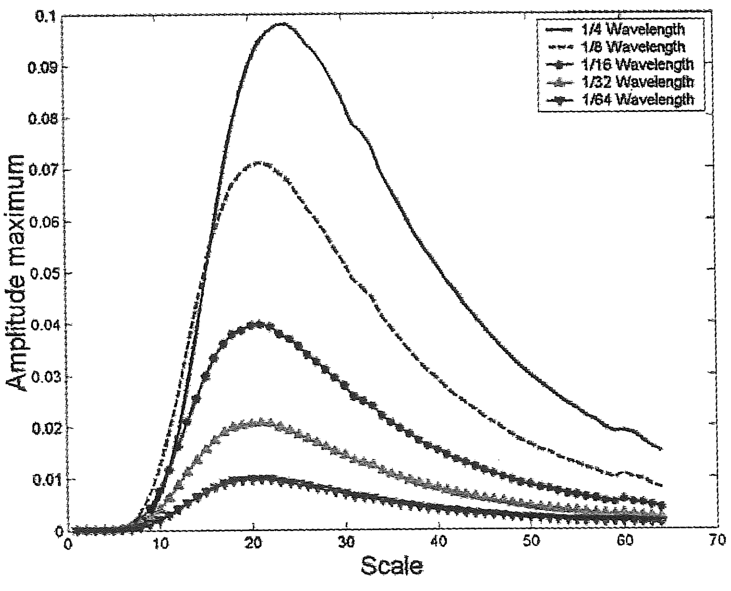

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Figure7 Amplitude versus scale for different bed thickness when incidence angle is 0 (a) and Amplitude versus scale for different bed thickness when incidence angle is 30(b).

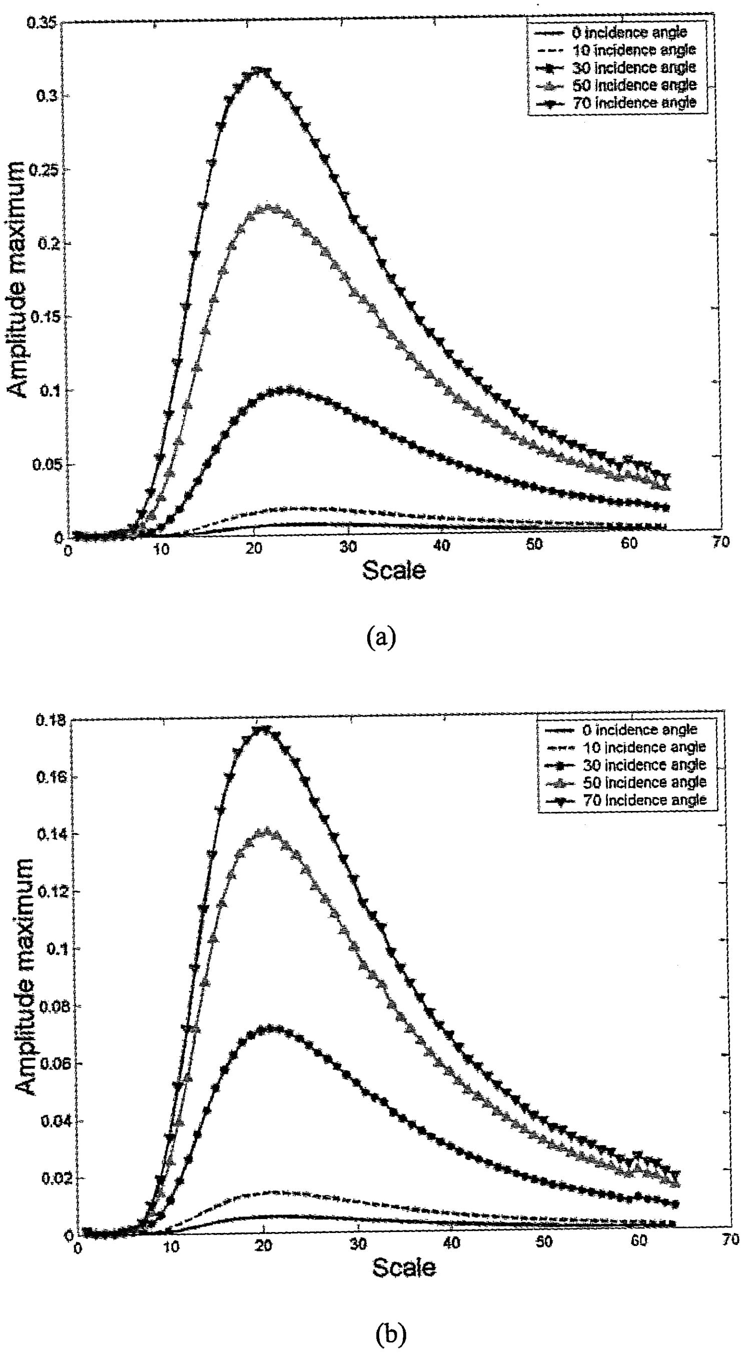
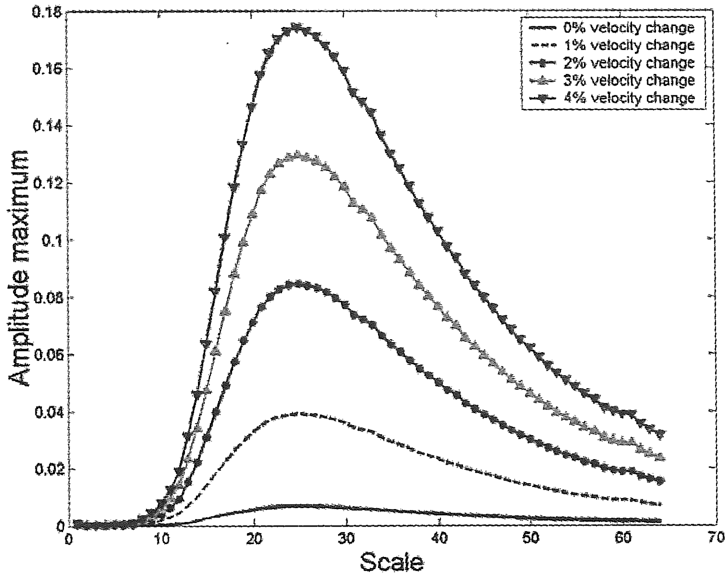


Figure8 Amplitude versus scale for different incidence angle when bed thickness is 1/4 wavelength (a) and Amplitude versus scale for different incidence angle when bed thickness is 1/8wavelength (b).



(a)

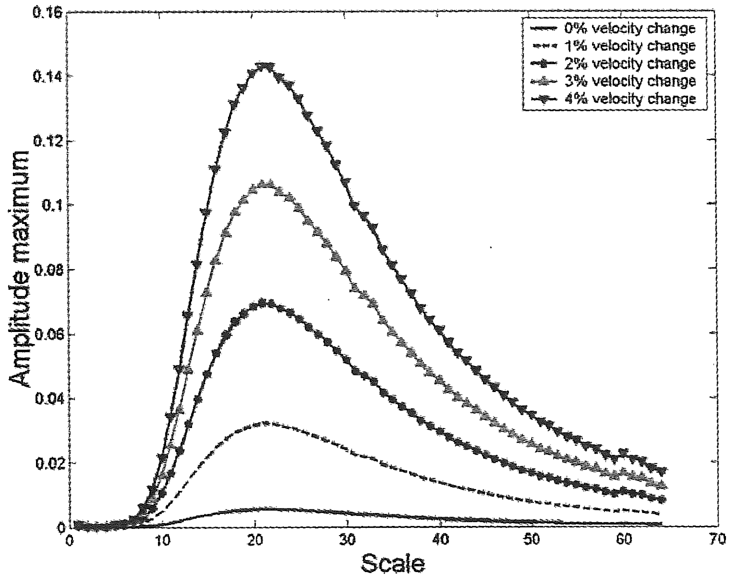


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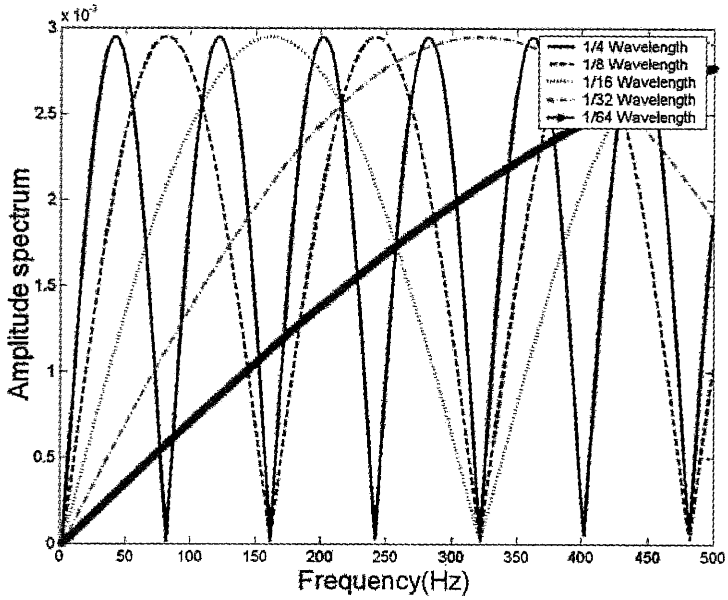
Figure9 Amplitude versus scale for different velocity change when bed thickness is 1/4 wavelength (a) and Amplitude versus scale for different velocity change when bed thickness is 1/8wavelength (b).

5 Reflection coefficient spectrum for thin-layer thickness and velocity change

Spectral decomposition has been successfully used in bed thickness estimation and fluid discrimination[13][14]. The basis of spectral decomposition is reflection coefficient spectrum dependence on thickness and velocity change. Using reflection coefficient spectrum, thickness and velocity change can be separated in thin-layer. Figure10-11 is reflection coefficient spectrum for different bed thickness and different velocity change. Bed thickness mainly affect frequency of reflection coefficient spectrum maximum. Velocity change mainly affect amplitude of reflection coefficient spectrum maximum. Using these two attributes, the bed thickness and velocity change can be discriminated.



(a)

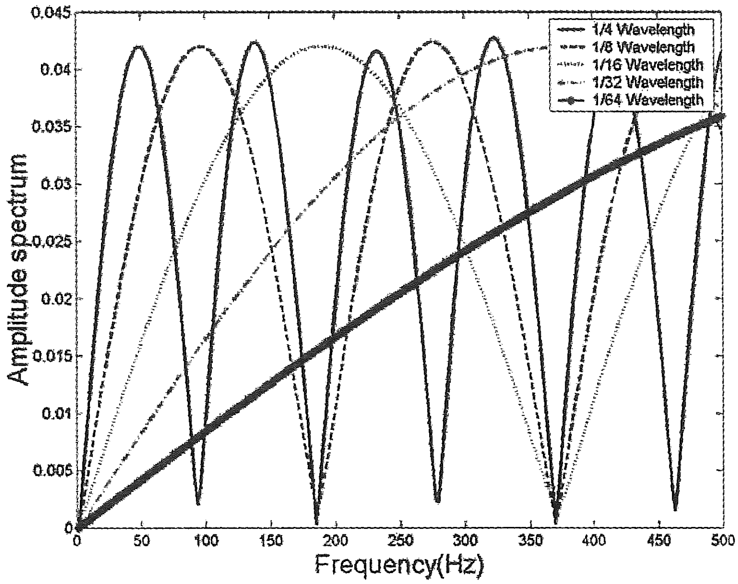


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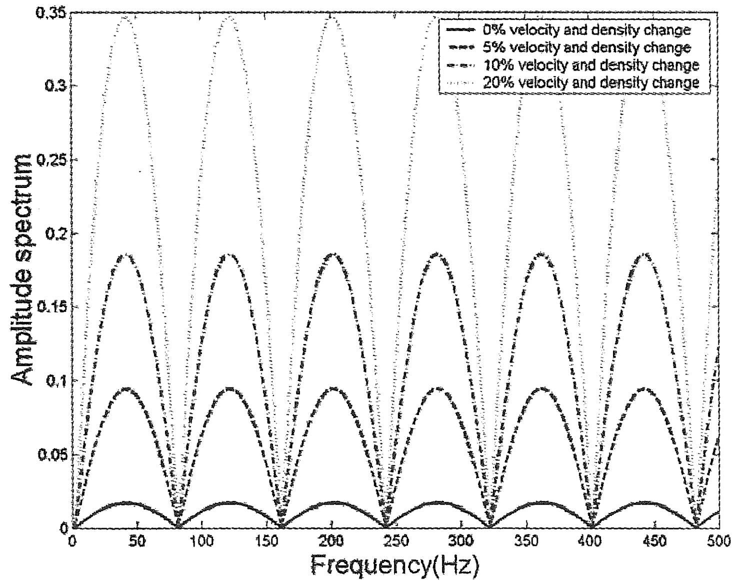
Figure10 Reflection coefficient spectrum for different bed thickness when incidence angle is 0(a) and Reflection coefficient spectrum for different bed thickness when incidence angle is 30(b).



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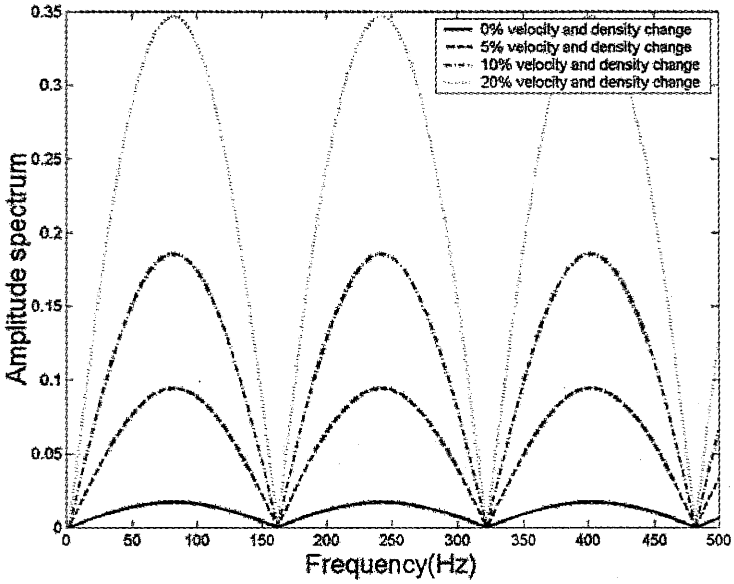

(b)

Figure11 Reflection coefficient spectrum for different velocity change when bed thickness is 1/4wavelength(a) and Reflection coefficient spectrum for velocity change when bed thickness is 1/8wavelength (b).

6 Time-frequency analysis for thin-layer

Time-frequency analysis can remove the tuning effect. The generalized S transform is used in the analysis. Figure 12 is the reflection coefficient and seismic trace. The seismic trace is affected by tuning. Figure 13 is the generalized S transform of the seismic trace. When the frequency increases, the spectrum has better correlation with reflection coefficient. Figure 14 is the comparison of one frequency spectrum and reflection coefficient. It can be shown that the position of maximum of spectrum can indicate the position of reflection coefficient. Figure 15 is the recovered reflection coefficient using time-frequency analysis. Time-frequency analysis is used to delineate the structure of seismic trace and combined with amplitude of the trace to form the recovered refection coefficient.

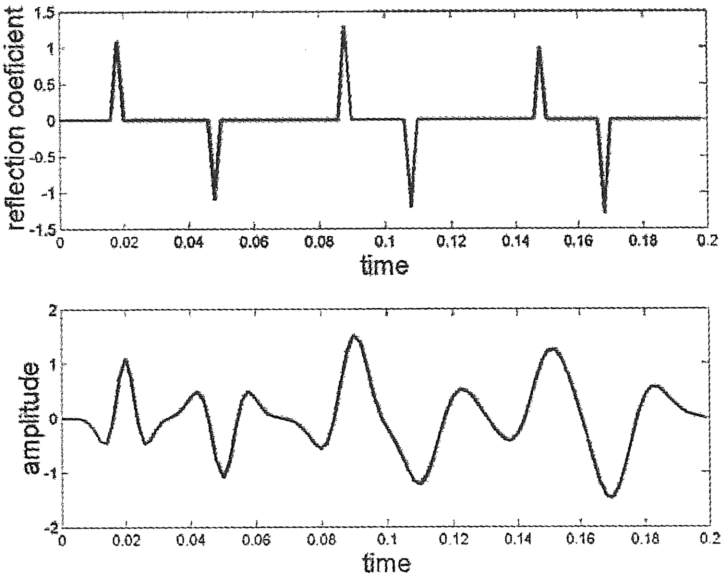

Figure12 Simple reflection coefficient and seismic trace

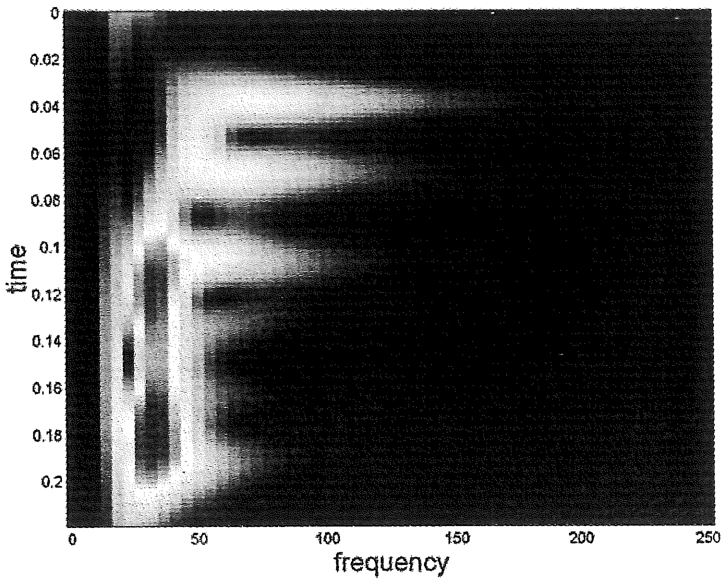

Figure13 Spectrum for the modeled seismic trace

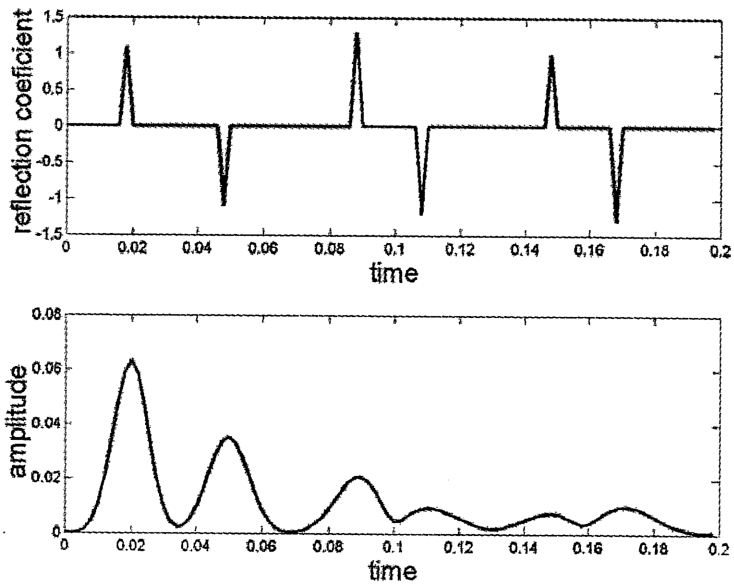

Figure14 Comparison of reflection coefficient and one high frequency spectrum

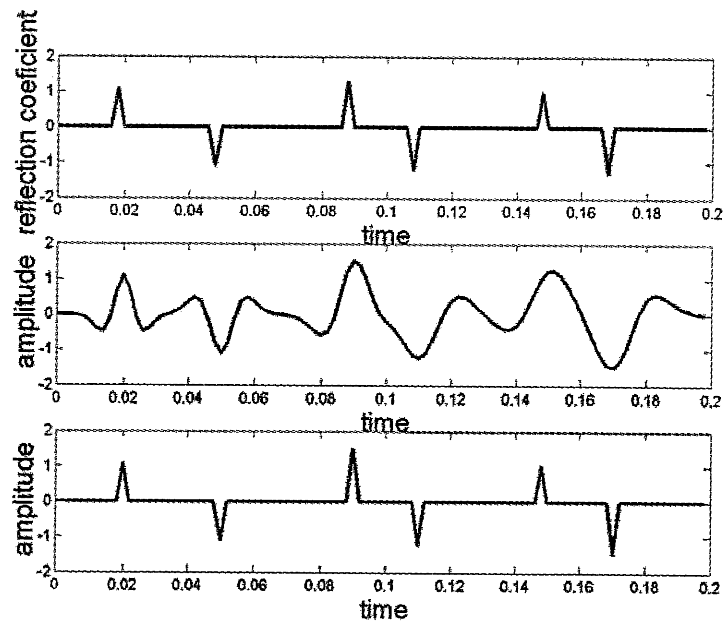

Figure15 comparison of recovered reflection coefficient and true reflection coefficient

7 Conclusions and discussions

The thin-bed seismic signature is affected by both bed thickness and reservoir property change. Using the proposed seismic attribute or combination analysis method, thin-bed reservoir can be characterized and monitoring more precisely.

Acknowledgement

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Appendix

For three layers model, the forum (1) can be derived using displacement and stress continuous conditions.

$$\begin{bmatrix} u^{(1)} \\ w^{(1)} \\ \sigma_{zz}^{(1)} \\ \frac{1}{2\mu_1}\tau_{zx}^{(1)} \end{bmatrix} = A_{ij}^2 \begin{bmatrix} u^{(3)} \\ w^{(3)} \\ \sigma_{zz}^{(3)} \\ \frac{1}{2\mu_3}\tau_{zx}^{(3)} \end{bmatrix}$$

$$u^{(1)} = -i\frac{\omega}{\alpha_1}\sin i_d^1 A_1^1 - i\frac{\omega}{\alpha_1}\sin i_d^1 A_2^1 - i\frac{\omega}{\beta_1}\cos i_s^1 B_2^1$$

$$w^{(1)} = -i\frac{\omega}{\alpha_1}\cos i_d^1 A_1^1 - i\frac{\omega}{\alpha_1}\cos i_d^1 A_2^1 - i\frac{\omega}{\beta_1}\sin i_s^1 B_2^1$$

$$\sigma_{zz}^{(1)} = -\rho_1\omega^2\cos(2i_s^1)A_1^1 - \rho_1\omega^2\cos(2i_s^1)A_2^1 + \rho_1\omega^2\sin(2i_s^1)B_2^1$$

$$\frac{1}{2\mu_1}\tau_{zx}^{(1)} = -\frac{\omega^2}{\alpha_1^2}\sin i_d^1 \cos i_d^1 A_1^1 + \frac{\omega^2}{\alpha_1^2}\sin i_d^1 \cos i_d^1 A_2^1 + \frac{\omega^2}{2\beta_1^2}\cos(2i_s^1)B_2^1$$

$$u^{(3)} = -i\frac{\omega}{\alpha_3}\sin i_d^3 A_1^3 - i\frac{\omega}{\beta_3}\cos i_s^3 B_1^3$$

$$w^{(3)} = -i\frac{\omega}{\alpha_3}\cos i_d^3 A_1^3 - i\frac{\omega}{\beta_3}\sin i_s^3 B_1^3$$

$$\sigma_{zz}^{(3)} = -\rho_3\omega^2\cos(2i_s^3)A_1^3 + \rho_3\omega^2\sin(2i_s^3)B_1^3$$

$$\frac{1}{2\mu_3}\tau_{zx}^{(3)} = -\frac{\omega^2}{\alpha_3^2}\sin i_d^3 \cos i_d^3 A_1^3 + \frac{\omega^2}{2\beta_3^2}\cos(2i_s^3)B_1^3 \qquad (1)$$

Where α_1 、 β_1 and α_3 、 β_3 is the p and s wave velocity. i_s^1、 i_d^1、 i_s^3、 i_d^3 are angle of refection s wave, reflection p wave, transmission s wave, transmission p wave.

A_1^1、 A_2^1、 B_2^1、 A_1^3、 B_1^3 is the displacement amplitude of incidence p wave, reflection p wave, reflection s wave, transmission p wave, transmission s wave.

The ratio of displacement amplitude can be defined as,

$$R_{pp} = \frac{A_2^1}{A_1^1} \qquad R_{ps} = \frac{B_2^1}{A_1^1}\frac{\alpha_1}{\beta_1} \qquad T_{pp} = \frac{A_1^3}{A_1^1}\frac{\alpha_1}{\alpha_3} \qquad T_{ps} = \frac{B_1^3}{A_1^1}\frac{\alpha_1}{\beta_3} \qquad (2)$$

Where, R_{pp} is reflection coefficient in frequency domain.