AVO Analysis of a Single Thinning Bed

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ABSTRACT

Synthetic seismograms are constructed with a Ricker wavelet of 50 Hz dominant frequency to represent a gradually thinning bed with equal magnitude and opposite polarity reflection coefficients in a homogeneous medium. A tuning thickness of λ/4 is observed for the PP data. AVO intercept and gradient crossplot analysis is studied for a shale embedded in sandstone and a sandstone embedded in a thick homogeneous shale unit. For a slow velocity thin layer above tuning thickness, the AVO crossplot results show a counter-clockwise rotation, indicating a negative correlation as the gradient decreases and the reflection coefficient magnitude increases. For the fast velocity thin layer, a clockwise rotation occurs in the AVO crossplot trend results as the bed thins. The gradient increases and the reflection coefficient magnitude decreases. Results below tuning thickness are less predictable, and could be misinterpreted as either a change in porosity or lithology.

INTRODUCTION

Thin bed reflection studies are important to evaluate resources in thin reservoirs, studying sedimentary processes, and interface resolution for structure mapping. Resolving and defining thin layers is difficult and challenging (Chang et al., 1996), and many approaches can be taken. Vertical seismic resolution is defined by Widess (1973) as the thickness equal to one eighth of the seismic predominant seismic wavelength. However, this threshold does not account for noise and wavelet broadening, so one quarter of the predominant wavelength is taken as an industry standard for thin bed vertical resolution. This vertical resolution threshold is also known as the tuning thickness, or tuning point, and is where maximum constructive amplitude occurs.

AVO analysis is useful in indentifying lithology, predicting pore fluid content, and evaluating hydrocarbon potential. The AVO effect is dependent on the petrophysical properties V_P, V_S, and density p. Crossplot analysis of AVO parameters such as a scatter plot of P-wave reflectivity (intercept) and the AVO gradient defined by Shuey's approximation of the Zoeppritz equations are useful in identifying linear trends in clusters of data for further analysis.

This study examines the case of thinning beds having equal magnitude and opposite polarity. Two geological models are investigated; a gradually thinning embedded lower velocity and density layer, and a gradually thinning embedded higher velocity and density layer in homogeneous media. Models of flat reflectors are created with a moderate acoustic contrast at the interfaces. AVO crossplot analysis investigates the reflectivity behaviour of thinning beds with offset.

THEORY

The Zoeppritz equations describe how the energy of a plane wave partitions into transmitted and reflected waves at an elastic interface between two isotropic and homogeneous half-spaces, relative to the incident angle. Shuey (1985) simplified the Zoeppritz equations to give the P-wave reflection coefficient as a function of angle of incidence:

$$R_{PP}(\theta) = A + B\sin^2\theta + C(\tan^2\theta - \sin^2\theta) \qquad (1)$$

where **A** represents the linearized zero-offset P-wave reflection coefficient, **B** is the AVO gradient which approximates reflection amplitudes at various offsets and depends on the sine of the angle of incidence squared, and **C** is the AVO curvature term which is dropped for angle of incidence greater than 30°. These coefficients are often used as AVO indicators for modelling studies (Castagna and Smith, 1994).

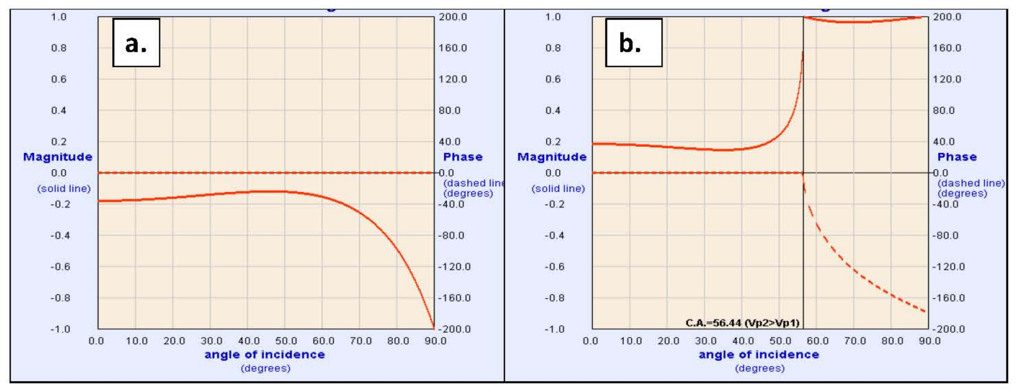

FIG 1. P-wave reflection coefficient compared to angle of incidence from the Zoeppritz explorer applet. The solid red line is the reflection coefficient magnitude, and the dashed line represents phase in degrees. A) Parameters shown for an interface with a sandstone top layer and a shale bottom layer. B) Model parameters for a top shale layer and a bottom sandstone layer. Since the Zoeppritz equations can only predict the reflection and transmission coefficients at a single interface, these equations are not suitable to study the amplitude and AVO response of a thin bed problem (Liu and Schmitt, 2003).

MODEL PARAMETERS

	Unit	Vp (m/s)	p (kg/m^3)	Vs (m/s)
Model I	Sandstone 1	3000	2650	1670
	Shale	2500	2200	1250
	Sandstone 2	3000	2650	1670
Model II	Shale 1	2500	2200	1250
	Sandstone	3000	2650	1670
	Shale 2	2500	2200	1250

Table 1. Geologic models used to investigate the response of a thinning bed.

	MODEL I	MODEL II
	Thickness (m)	
3λ	250	180
λ	83.3	60
λ/4	20.8	15
λ/8	10.4	7.5
λ/10	8.3	3.8

Table 2. Thin bed thickness based on dominant frequency of 50 Hz.

SEISMOGRAM PARAMETERS

- Zero-phase Ricker Wavelet (50 Hz)
- Sample rate = 0.002 s
- NMO removed
- 100 m geophone spacing, 1500m offset
- Max offset-depth ratio = 1.5

RESULTS

MODEL I

The reflection points follow a counter-clockwise rotational trend above tuning thickness, and amplitude decreases with offset. However, as the bed continues to thin below tuning, the results could lead to misleading interpretations.

MODEL II

An amplitude peak occurs on the top of the Sh-SS interface, and a trough on the bottom SS-Sh interface. As the sandstone bed thins, the Intercept-Gradient crossplot rotates clockwise. Amplitude decreases with minimum offsets.

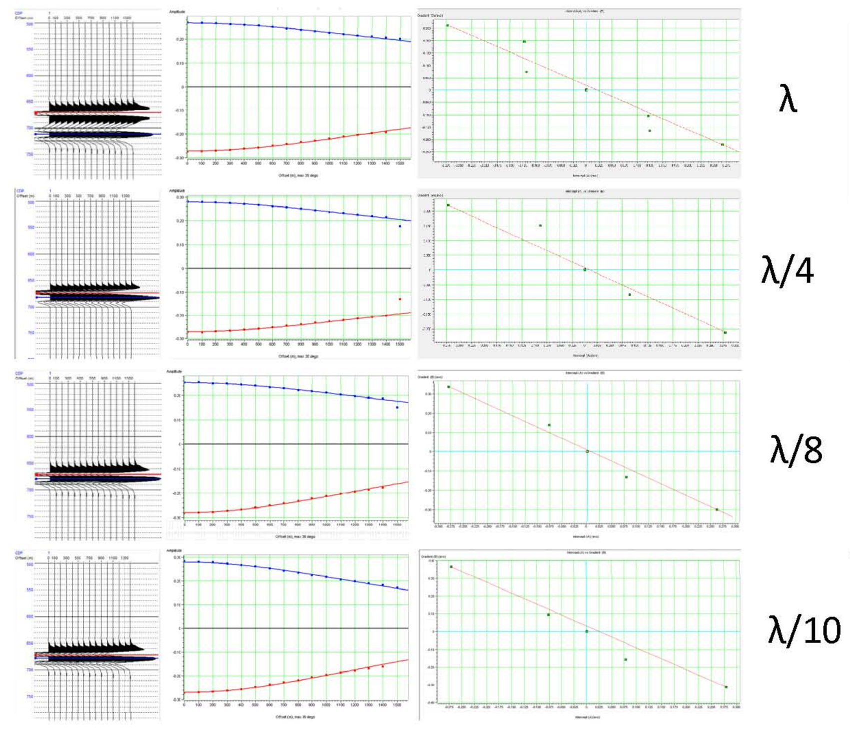

FIG 2. AVO analysis showing PP-reflection seismograms of various thicknesses. A linear trend is drawn between intercept-gradient points based on the trough and peak time picks.

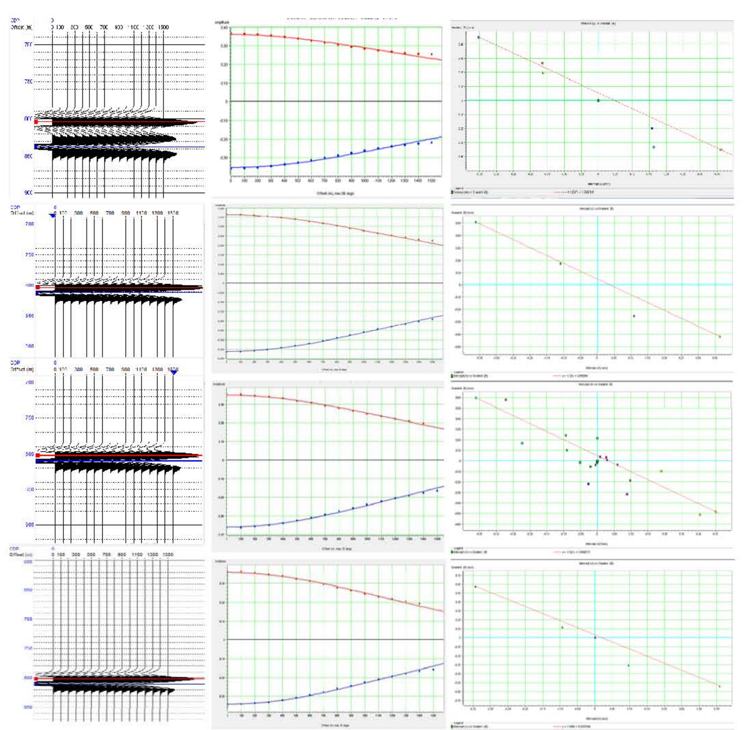

FIG 4. A linear trend is drawn between intercept-gradient points based on the peak and trough time picks. Note at < λ/4, it is difficult to resolve the thin bed interfaces.

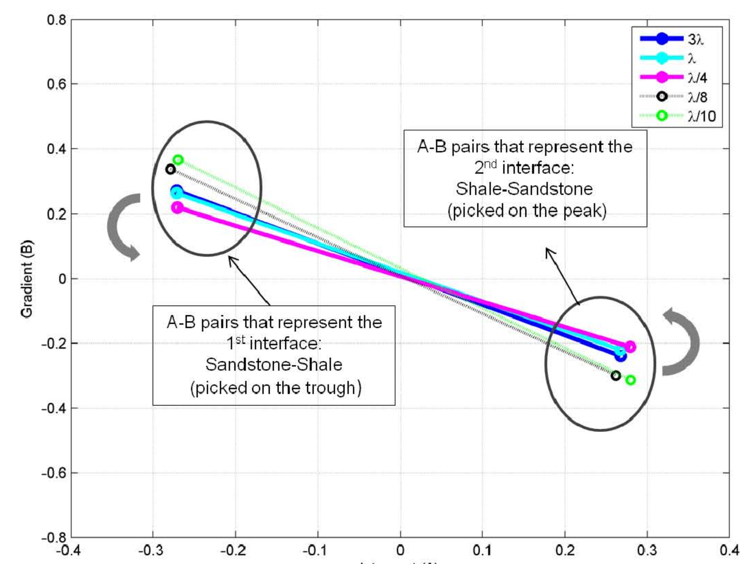

FIG 3. Intercept-Gradient cross-plot for Model I. A counter-clockwise rotation in trend as bed thickness decreases from 3λ until λ/4 . As the bed continues to thin past tuning thickness, the results are less predictable.

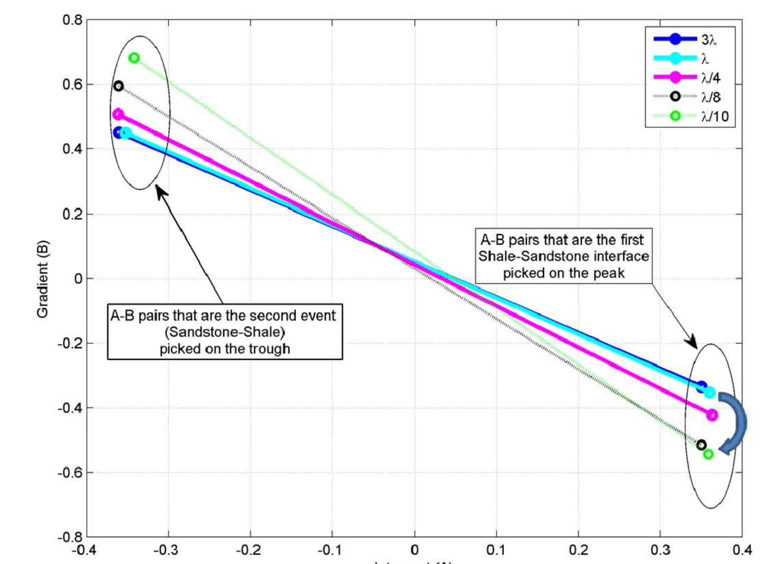

FIG 5. Intercept-Gradient cross-plot for Model II. A general clockwise rotation occurs as bed thickness decreases. the single reflection points past tuning could be interpreted as a change in lithology (as the gradient and intercept are lowered)

CONCLUSIONS

Two cases of each a slow and fast velocity thin layer embedded in a homogeneous medium is modelled as a synthetic seismogram with equal magnitude but opposite polarity. Thin beds below tuning thickness cause limitations and complexities in the theoretical analysis of the Zoeppritz reflection coefficients and AVO crossplot analysis as the top and bottom interfaces of the thin layer converge. Variations in the AVO crossplot due to tuning thickness can be misinterpreted as either a change in porosity or lithology.

Future work includes exploring unequal polarity or strength models, and multiple beds. Also, by further investigating frequency and enhancing the spectral bandwidth of the seismic data, the theoretical limits of resolution can be improved and tuning thickness further decreased (Chopra et al., 2006). Using a 90 degree Ricker wavelet is proposed by Zeng (2009) to focus more on resolving the bed itself, rather than the interfaces to identify thickness.

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