Interpretation of thin beds in spectral domain: A case study

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Abstract

The number of beds and their thicknesses in nature are governed by fractal relationships. This implies that in geology, thinner the beds higher the number of beds present. Characterization of thin beds on seismic data has always been an important challenging task faced by the industry as significant amount of hydrocarbons are trapped in them.

Resolution of beds in time domain is limited as seismic data is band limited (Widess, 1973). Studying responses in alternate spectral domain adds value to the interpretation of thin beds. The study in spectral domain pertains to Indian offshore field where maximum amplitudes at low frequency in the range of 10 to 20 Hz were observed relating to reservoirs, and was utilized to delineate and explore them. Higher time thicknesses in the range of 50-25ms are required to explain the maximum amplitudes at these lower frequencies, which were not supported by log data. Rather two reservoir layers of thickness in the range of 3-10m each embedded in shale was observed to be present in most of the cases. Therefore, model consisting of two reservoir layers embedded in shale was built to analyze the observations in spectral domain by generating synthetic response. Results showed thickness of individual layers and effective separation between them governs the frequency of highest amplitudes, explaining the occurrence of highest amplitudes at lower frequencies.

Methodology

Thickness less than tuning thickness T is defined as thin; $T = 0.389/f_o$ ms, where f_o is dominant frequency in the data(Chung and Lawton 1995). We started with the most basic conceivable model of a thin sand bed embedded in a shale back ground. The reflectivity from the top and bottom of the sand bed were assumed to be +1and -1 respectively. A Ricker wavelet of dominant frequency 30 Hz and unit peak amplitude at time zero was generated. The amplitude spectrum of 30 Hz Ricker wavelet has negligible amplitudes beyond 80 Hz. A trace was generated by the convolving reflectivity series.

$$s(t) = w(t) * g(t) \qquad \text{(I)}$$

Where s(t) represents trace, w(t) wavelet, g(t) reflectivity and symbol *convolution respectively. An amplitude spectrum was also generated by applying Fourier transform. Therefore,

$$g(f) = s(f)/w(f) \qquad \text{(II)}$$

Where g(f), s(f) and w(f) represents Fourier Transform of g(t), s(t) and w(t) respectively. The minimum twt bed thickness (T) which can be resolved is given by:

$$T = 1000/(2*f_r) \qquad \text{(III)}$$

Where f_r is the higher limit of the frequency bandwidth of g(f). A study is carried out to identify thin bed relating amplitudes on the trace (in time domain) to their amplitude spectrum (frequency domain). Deconvolution was carried out in frequency domain:

So, the highest frequency available in the data defines the limit of resolution for a single layer in spectral domain as:

$$T = 1000/(2*80) = 6.25 \text{ ms (milliseconds)}$$

Forward Modeling of amplitude spectrum and Interpretation

A model was conceived by constituting a pair of thin beds (two layers) embedded in shale (Figure 1). A parameter 'effective separation' was defined as the time interval between the tops of the two thin beds. Two models having bed thickness of 3ms each with effective separation of 7ms therefore called as 3-4-3 (3ms sands separated by 4ms of shale) and other having bed thickness of 5ms each with effective separation of 7ms therefore called as 5-2-5(5ms sands separated by 2ms of shale) are shown to illustrate the point.

We propose a scheme that resultant reflectivity amplitude spectrum (after Deconvolution) is the product of

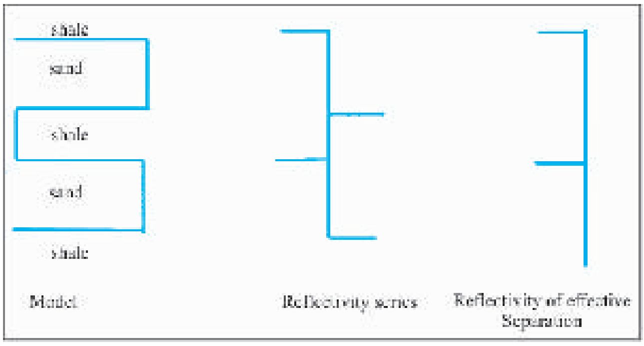

Fig. 1: Model constituting of pair of thin beds (two layers) embedded in shale and corresponding reflectivity series and reflectivity of effective separation.

the weighted sum of individual reflectivity amplitude spectra and the reflectivity amplitude spectrum of effective separation. We constructed reflectivity amplitude spectrum (g) using the reflectivity amplitude spectra of individual bed thicknesses

$$P(f) = (W_1(f) \times g_1 + W_2(f) \times g_2) \times g_e = g \qquad ....(IV)$$

Where W_1, W2 = Weighting factor such that $W_1(f) + W_2(f) = 1$, g_1, g_2 = Reflectivity Amplitude spectra of individual beds. (In case of symmetry $g_1=g_2$), g = Reflectivity Amplitude spectrum of the model, g_e= Reflectivity Amplitude spectrum of effective separation and P(f) = product of weighted sum of reflectivity amplitude spectra of individual beds with reflectivity amplitude spectrum of effective separation. For symmetric case i.e. thin beds of equal thicknesses the weighting factors are equal and 0.5.

We use the forward modeling concept to interpret for the presence of thin beds using amplitude spectra. The global minimum of the reflectivity amplitude spectrum (g) corresponds to the minima of reflectivity amplitude spectrum of effective separation (g_e). This enables us to infer the effective separation of an unknown model. Rewriting the equation (IV) as

$$Q(f) = g/ g_e = (W_1(f) \times g_1 + W_2(f) \times g_2)$$

Where Q is the ratio of reflectivity amplitude spectrum of model to that of effective separation. For symmetric models the weighting factors are independent of frequency and are equal. The Q is same as that of reflectivity amplitude spectrum of individual sand layer (g_1).

The illustrations in figure2and figure3 show that scheme of reflectivity amplitude spectrum can be evaluated in term of amplitude spectrum of individual beds and that of effective separation.

Figure 2 a) Amplitude spectrum of 3-4-3 model s(f)), b) Reflectivity amplitude spectrum of 3-4-3 model (g), c) Reflectivity amplitude spectrum of 3ms layer (g_1), d) Reflectivity amplitude spectrum of 7ms effective separation (g_e), e) product of c and d, f) $Q = g/g_e$

Conclusions

Scheme for interpretation defined above enhance the thin bed resolution (within a succession of thin beds) using spectral deconvolution. Beds can be resolved in the spectral domain as long as the effective separation is greater than or equal to $1000/2*f_r$; Where f_r is the higher limit of frequency band.

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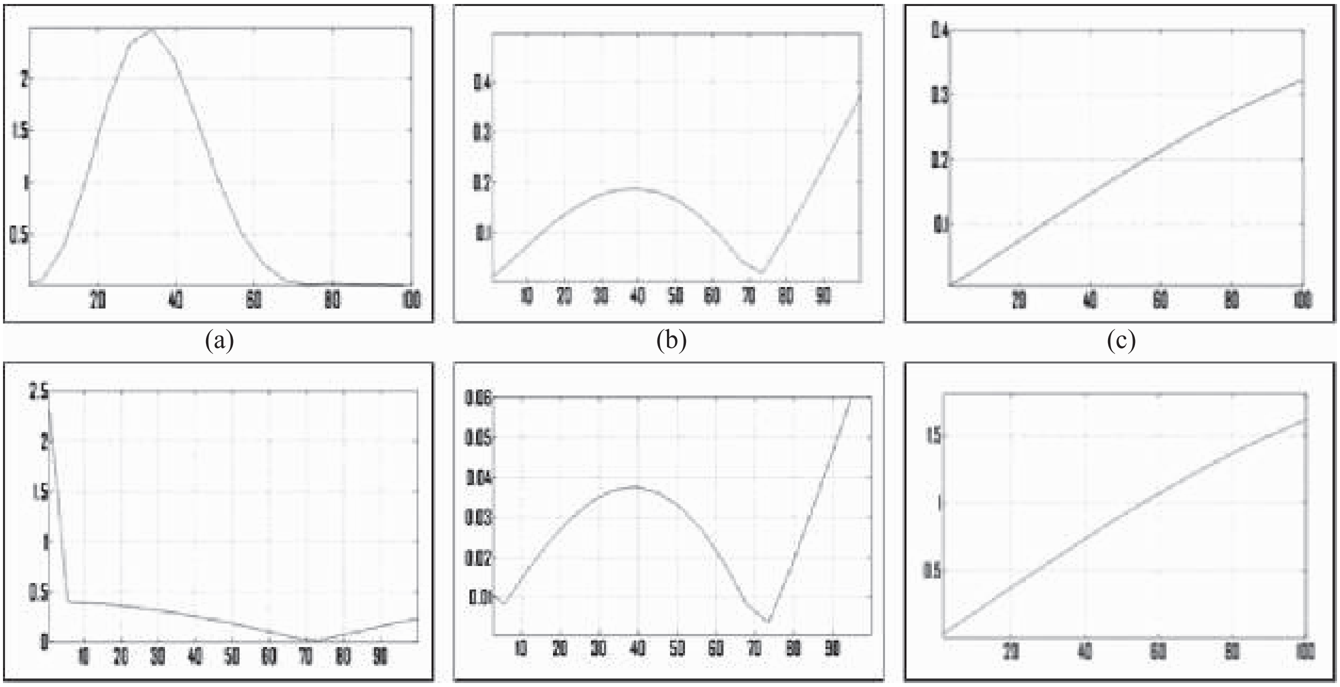
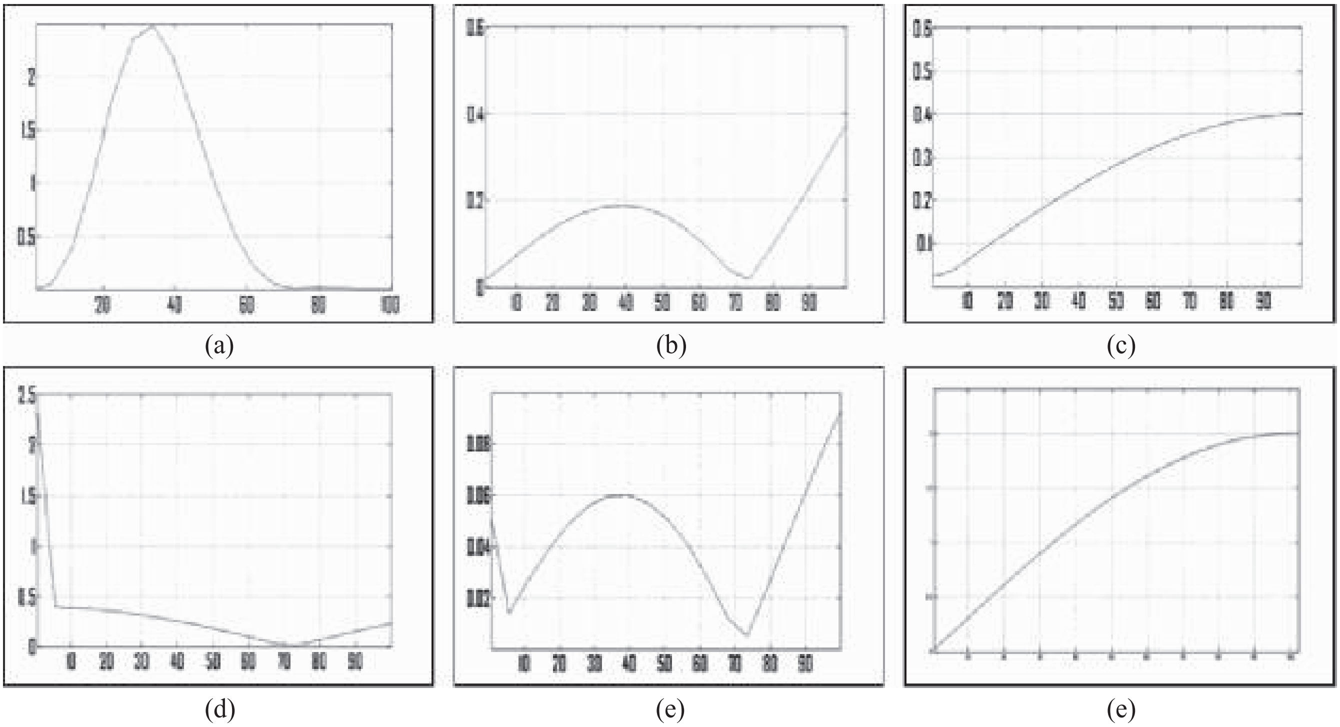


(a) (b) (c)

(d) (e) (e)

Fig.2: a) Amplitude spectrum of 3-4-3 model s(f)), b) Reflectivity amplitude spectrum of 3-4-3 model (g), c) Reflectivity amplitude spectrum of 3ms layer (g_1), d) Reflectivity amplitude spectrum of 7ms effective separation (g_e), e) product of c and d, f) $Q = g/g_e$



(a) (b) (c)

(d) (e) (e)

Fig.3: Amplitude spectrum of 5-2-5 model (s), b) Reflectivity amplitude spectrum of 5-2-5 model (g), c) Reflectivity amplitude spectrum of 5ms layer (g_1), d) Reflectivity amplitude spectrum of 7ms effective separation (g_e), e) product of c and d , f) $Q = g/g_e$

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Suggested Readings

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