Spectral decomposition for recognition of subtle depositional elements in deepwater fans: A case study from Krishna Godavari Basin, India

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Keywords

Spectral Decomposition, Continuous Wavelet Transform, Tuning Frequency

Summary

Spectral decomposition of seismic data by wavelet transform is a common and useful tool for resolving features having thickness less than seismic limit of resolution. For thin reservoirs, estimation of tuning frequency can be made by utilizing spectrally decomposed volumes at different frequencies. In a virgin area, with 3D seismic data, this technique can be applied by analyzing depositional patterns in different frequency bands for high resolution mapping of depositional elements and a postulation of facies variation within them can be achieved.

Continuous Wavelet Transform (CWT) unlike Short Wavelet Fourier Transform (STFT) has greater control over frequency and time resolution of a non stationary signal. This is the reason why spectral decomposition of seismic data using CWT is the preferred and widely used method.

Utilization of spectrally decomposed bands for unraveling the Paleocene depositional system in deepwater Krishna-Godavari basin in India, aided in detailed mapping of various depositional elements and subtle facies variations within them. Through mapping and sequential slicing of the Paleocene sequence a full depositional cycle of basin floor progradation – retrogradation is interpreted.

Introduction

The deep-water Krishna Godavari basin, located along the passive Eastern Continental Margin of the Indian plate, is fed by the sediments derived from the Krishna and Godavari rivers and the Bengal Fan. The study area of 2211 SKM, lies nearly 250 km away from present day shelf edge (Fig. 1). Oceanic crust underlies the study area and the volcanic 85°E Ridge flanks it towards the east and southeast. The analysis of a distal fan of Paleocene age and its evolution is mapped by amplitude slicing of spectrally decomposed data.

Methodology

The continuous wavelet transform of a non stationary time series x(t) is defined as follows (Christopher Liner, 2010):

$$CWT_x^{\Psi}(\tau, s) = \Psi_x^{\Psi}(\tau, s) = \frac{1}{\sqrt{s}} \int x(t) \Psi^* \left(\frac{t-\tau}{s}\right) dt$$

Above transformed signal, is a function of two variables, tau (τ) and s, the translation and scale parameters respectively. Ψ(t) is the transforming function and it is called the mother wavelet. Unlike STFT, window function used in CWT is oscillatory. The term translation is related to the location of the window that is shifted through the signal. Parameter scale in the wavelet analysis is related to the frequency of the signal. Low frequency corresponds to high scale and high frequency corresponds to low scale.

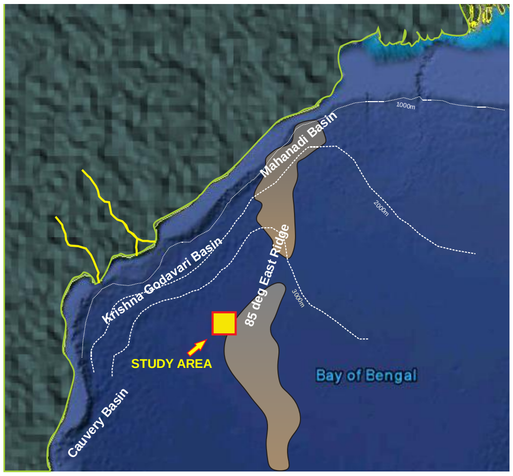

Figure 1: Location of study area.

The mother wavelet is chosen to serve as a prototype for all windows in the process. All the windows that are used, are dilated (or compressed) and shifted version of mother wavelet. There are a number of wavelets that are used for this purpose. For present study a Gabor wavelet is used as a mother wavelet and all the frequency bands are derived with different scaling factors applied on Gabor wavelet. This wavelet when convolved with seismic trace will give peak amplitude at frequencies close to the central frequency of the Gabor wavelet. Hence with different scaling factors (frequencies) applied on Gabor wavelet, different frequency band volumes can be derived from a PSTM seismic volume. Frequency bands used for the present study are listed in Table-1.

	Fmin	Central Frequency	Fmax
Band 1 (10 hz)	4	12	21
Band 2 (20 hz)	12	20	27
Band 3 (30 hz)	16	30	37
Band 4 (40 hz)	28	35	43
Band 5 (50 hz)	32	40	52

Table 1: Classification of frequency bands within interval

Classification (Table-1) is based on range of frequency and number of bands required for the interpretation. Range of frequency depends on frequencies present in the seismic data. A frequency band having a central frequency higher than seismic range will not yield any useful information as Gabor wavelet for that band will not find similarity with the traces.

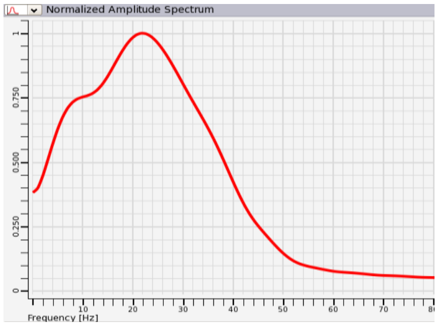

Figure 2: Amplitude spectrum of PSTM data around interval of interest (near Paleocene Top).

A frequency higher than 50 Hz does not show much contribution to amplitude (Fig. 2), therefore range is chosen from 0 to 50 Hz with 10 Hz increment for each band.

The Paleocene sequence is analyzed with 20ms horizon slicing from 100ms above the Paleocene top to 200ms below it (Fig. 3), in the bands given in Table 1 and evolution of various elements in the depositional system are analyzed.

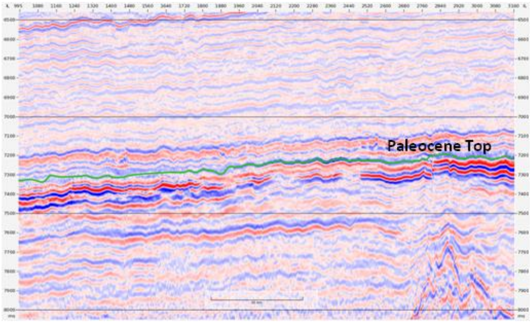

Figure 3: Section used for computation of frequency range of bands.

Geological Setting

Krishna-Godavari (K-G) basin is located along the eastern continental margin of India. Basin contains sediments ranging in age from Lower Permian to recent. The basin received sediments from the K-G dispersal system, in the passive margin phase from the Mid-Cretaceous onwards. From the Oligocene-Miocene times the basin receives sediments from the KG and the Bengal Fan systems. In KG basin offshore, structures are primarily related to sediment loading and subsequent collapse of shelf edge, which formed genetically, linked growth faults and toe thrust pairs, near the shelf edge, while in the distal parts of the basin it is relatively undisturbed. The studied area lies in the distal deep water, basin floor of the basin.

Paleocene Frontal Splay System

Present study deals with a Paleocene basin floor channel-levee frontal splay complex in the distal part of the basin. The generated 20ms horizon slices with reference to the Paleocene top are projected on to the seismic section (Fig. 4). The depositional features are subtle and contained within individual seismic events. The evolution of the depositional system is analyzed from near the Cretaceous top to the top of Eocene, based on frequency response on a representative horizon slice +/-10ms from Paleocene top. The basal Paleocene sediments are largely pelagic, while higher up in the sequence, a channel-splay system is present. The system ceases and pelagic sedimentation takes over in the lower parts of the Eocene times.

Frequency response of depositional elements

RMS amplitude map of Paleocene top is analyzed, as a representative of the system, on full band PSTM, 10, 20, 30, 40 & 50Hz volumes. Paleocene top has a dominant frequency around 23 Hz (Fig. 2). The amplitude response relatively decays in frequencies higher than 20Hz, indicating that most depositional features have thicknesses less than the tuning thickness. RMS amplitude horizon slice generated +/-10ms from the Paleocene top (Fig. 5a to f), illustrate the resolution of different depositional elements in the selected 10Hz increment bands with the normal PSTM.

In the NE quadrant of the map, a shoe-string feeder channel with a frontal splay is seen (Fig. 5). Amplitude response of this channel-splay suggests presence of coarser sediments than the surrounding, which has a low amplitude response. In the PSTM slice (Fig. 5a) the full extent of the bright frontal splay is seen, while the feeder channel is broadly resolved. In 10Hz (Fig. 5b), only the core of the splay is resolved, while in 20Hz (Fig. 5c) the core of the splay and the channel are resolved. The 30Hz slice (Fig. 5d), resolves details of the feeder channel, including small distributaries and a western branch, which remains unresolved in lower frequencies. The 40Hz slice (Fig. 5e), resolves the western branch and disconnected elements of the feeder channel, while the 50Hz slice (Fig. 5f) fails to resolve the splay and feeder channel. For most part, the feeder channel and splay seem to have a tuning frequency around 20 to 30 Hz.

In the western half of the area, a broad radiating area with numerous channels is present. These channels pass through the area further to the south and are interpreted to represent a by-pass of sediments through the area to the south. Most of these channels are identifiable due to high amplitudes developed on their edges, and are likely to be clay filled. Comparing to the channel splay system, it can be seen that details of these radiating channels are better resolved in the higher frequencies up to 50Hz, as compared to the lower frequency bands (≤20Hz) and the PSTM. The likely cause of this is that the channels have low thickness as seen from the seismic section (Fig. 5), to be contained within a single seismic event.

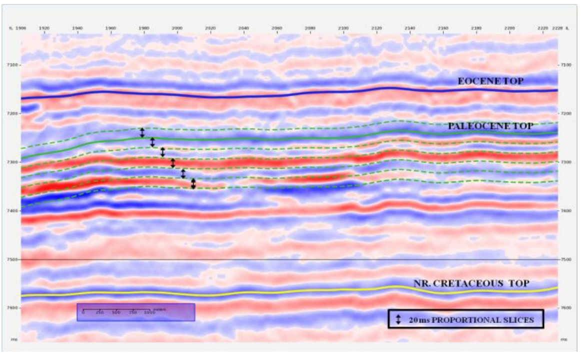

Figure 4: Seismic section showing horizon slices used for interpretation.

Evolution of the depositional system

The evolution of the depositional system was analyzed on all the generated volumes and results from the 30Hz volume are illustrated as it is more representative of the average tuning thicknesses of the depositional elements.

In the early part of Paleocene the sedimentation is largely pelagic as represented by a relatively monotonous low amplitude response. Higher up in the sequence a broad SSW expanding splay system appears in the northern parts of the area, which is distinguishable by the relatively higher amplitudes. The broad splay gets dissected by southerly flowing channels further up in the sequence (Fig 6). 100-200ms below the Paleocene top, the channels are interpreted to be largely filled by variable lithologies (clayey/sandy) as indicated by presence of low to medium amplitudes. Further up in the sequence these channels erode and cut into the older splay and a braided to distributaries spread over the area, 60-80ms below the Paleocene top (Fig 7). These appear to be largely clay filled due to low amplitude response of these features. This would represent progradation of the system, the older splay being eroded by channels and the sediments bypassing the area to further downstream to the south.

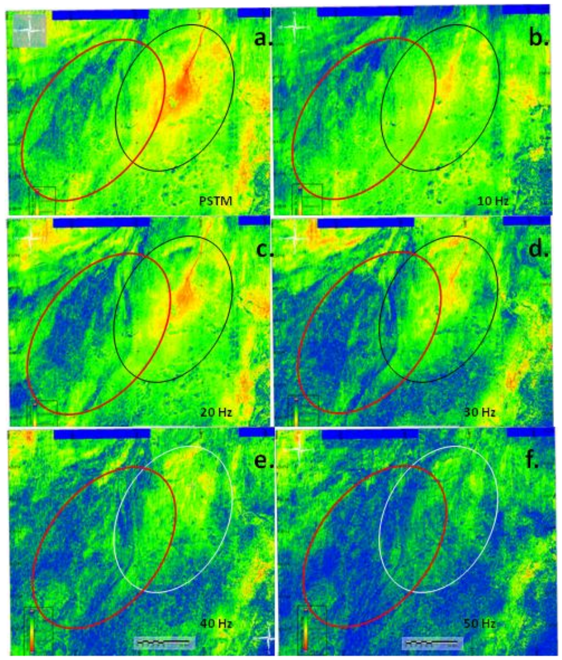

Figure 5: Differential resolution of a frontal splay and by-pass channels in RMS slices +/-10ms from Paleocene top. a. Full band PSTM, b. 10 Hz, c. 20 Hz, d. 30 Hz, e. 40 Hz and f. 50 Hz.

Horizon slice 20-40ms below Paleocene top (Fig 8) shows weakening of the clay filled channel system and appearance of a fresh set of smaller sized channels in the northern part of the area. These channels develop frontal splays, which have a high amplitude response, indicating presence of coarser clastic sediments. There appear to be three separate splay systems, a southwesterly trending system in the western part, a southerly trending system in the central part and a southeasterly trending system in the eastern part. The final phase of the splay-feeder channel system is seen in the slice at the Paleocene top (Fig. 5), where the south-westerly trending central system is prominent, with a feeder channel splitting into two distributaries and a prominent frontal splay. This phase of the system is interpreted to represent headward retrogradation of the depositional system.

Final abandonment of the system is seen in the slice 20ms above the Paleocene top (Fig. 9). The slice intersects topmost part of the central splay-feeder complex. A large fanning channelized system present in eastern part is interpreted to represent passive pelagic filling of the channels, as no fresh erosive features can be seen in the seismic sections. Slices further up show a largely low amplitude response, without any discernible major depositional elements indicating dominance of pelagic sedimentation. A full cycle of progradation – retrogradation is thus seen in this Paleocene basin floor fan system.

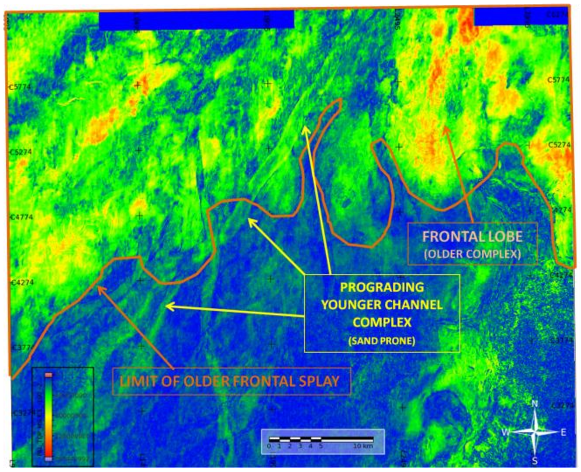

Figure 6: RMS Amplitude at 30 Hz, 100-120 ms below Paleocene top.

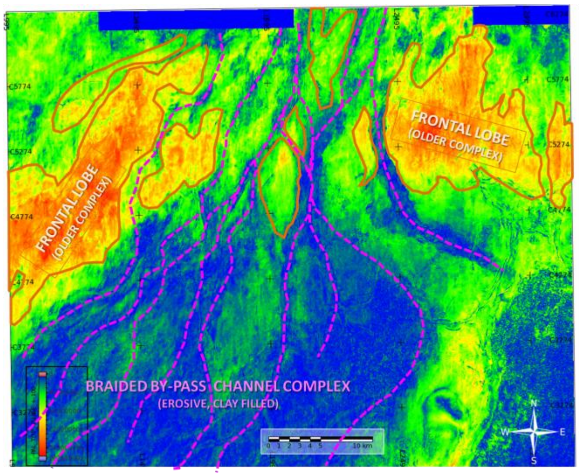

Figure 7: RMS Amplitude at Hz 30, 60-80 ms below Paleocene top.

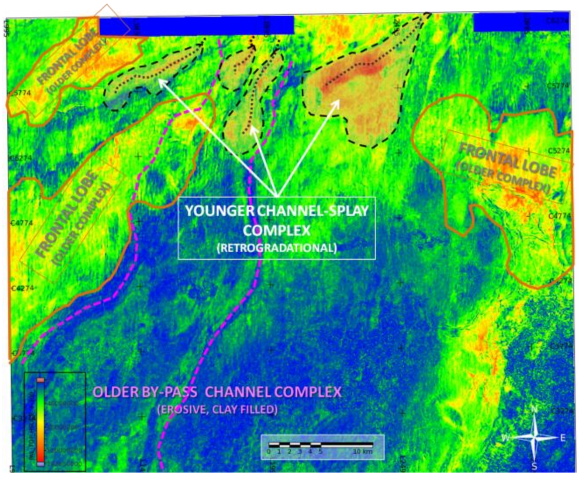

Figure 8: RMS Amplitude at 30 Hz, 20-40 ms below Paleocene top.

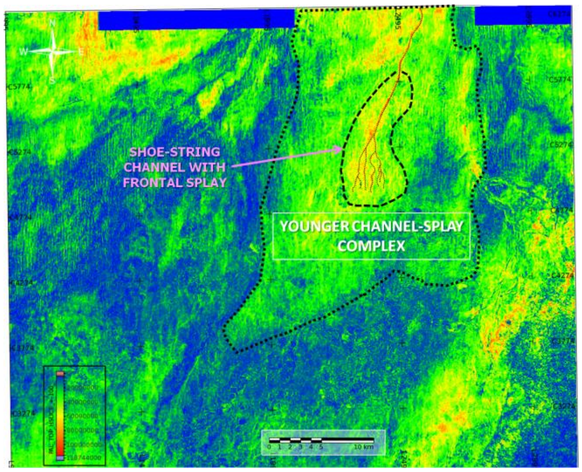

Figure 9: RMS Amplitude at 30 Hz, 20 ms above Paleocene top.

Conclusions

Majority of the depositional features in the Paleocene sequence are well resolved in 30 Hz band. These features are interpreted to contain both coarse clastic as well as fine clastic lithologies. On the other hand in the 50Hz band, subtle features in dominantly finer clastic lithologies are resolved.

The Paleocene sequence starts with pelagic deposition, followed by evolution of a basin floor fan system. A full cycle of the fan progradation and retrogradation ending in abandonment and re-establishment of pelagic conditions is present in the sequence.

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