Application of Seismic Facies Classification, Spectral Decomposition and Seismic Attributes to characterize deep-water depositional facies in Oligocene sequence of KG Basin, India

Arnab Nag, Divya Prakash Singh, Anshika Agarwal, Shiv Kumar Malasi, Anand S. Kale*
BPRL, Mumbai
arnab.nag@bharatpetroresources.in

Keywords

Seismic Facies classification, Spectral decomposition and Volume Fusion

Summary

The objective of the study is to decipher the sediment dispersal system and depositional facies, within a distal deepwater, Oligocene sequence in the Krishna-Godavari Basin. A work-flow is designed to integrate outputs from seismic facies classification, spectrally decomposed volumes and basic amplitude attributes to discern and map subtle variations of depositional facies in a basin floor channelized dispersal system. The work-flow was tested on +/- 4ms window along a mapped horizon, within a 3D PSTM volume and later applied to the studied interval. Integration of these outputs finally resulted in the facies characterization of the Oligocene sequence. A southwesterly flowing channel system is present in the area, with associated overbank facies. For most part, the channels are confined to single seismic cycles and hence their identification by a single method is constrained due to vertical resolution of the seismic trace. The channels are mostly sinuous and meandering, while some are relatively straight and shoe-string type. Spectrally decomposed volumes with central frequencies of 10, 20 & 30 Hz, individually bring out different features, depending upon the thickness of the depositional elements. Seismic facies classification on the other hand uses trace shape (frequency and phase being integral to it) to bring out broad facies classes, which can be attributed to lithologies, interpreted by RMS maps derived from spectral volumes. RGB blending of spectrally decomposed volumes on the other hand combines the response obtained from individual spectral bands to generate maps for characterizing the facies. Analysis of the resultant data set reveals the presence of broad meandering channels dominantly responding to low frequency bands, with variable fills of sand and clay, which are also deciphered in the seismic facies maps. The other set of channels which are relatively straight in their course and are resolved in higher frequencies are likely to be clay filled. These channels are especially better distinguished with seismic facies classification as compared to spectral decomposition or RGB blending.

Introduction

In last two decades the deep water sector of Krishna-Godavari Basin (KG) Basin has been analyzed through various modern techniques to reveal its hydrocarbon prospectivity. In present study in deepwater environment of KG Basin a workflow is developed to analyze seismic data combining spectral decomposition, RGB blending and seismic facies for mapping of depositional facies.

The study area (~1020sq.km, Figure 1) is located in distal part of deep water KG Basin. The volcanic 85^{o}E ridge flanks the area to the East and SE, while the Eastern Continental Margin of the Indian plate is present to the west. The Oligocene interval is significant in the history of the basin as this time period witnessed the welding of Indian Plate with Eurasian plate (Himalayan Orogeny). The Indian plate (Peninsular India) experienced a change in

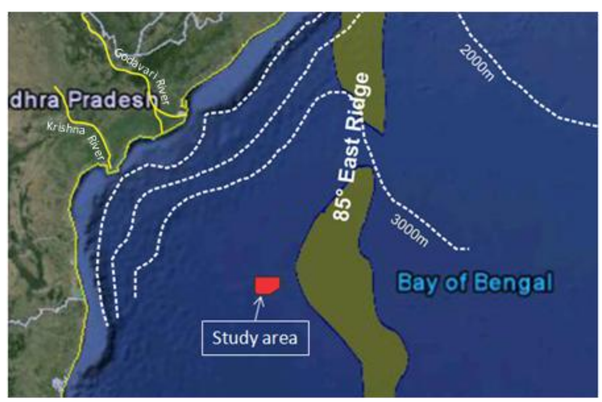

Figure 1: Location of the study area.

discharge of river systems due to the associated uplift. In the deep water, the main effect of this tectonic event is the change over from dominantly pelagic sedimentation to turbidity driven channelized dispersal systems originating from the ancient Krishna, Godavari, Mahanadi and evolving Ganges-Brahmaputra inflows. The objective of the paper is to study the sediment dispersal system within Oligocene sequence through integrated application of Neural Network based seismic facies classification and amplitude attributes analysis along the horizon with Spectrally Decomposition technique.

Methodology

Spectral Decomposition:

Spectral decomposition has been used in seismic interpretation for many years and there are quite a few methods available for spectral decomposition e.g. DFT (Discrete Fourier Transform), MEM (Maximum Entropy Method), CWT (Continuous Wavelet Transform) and MPD (Matching Pursuit Decomposition) (Castagna, and Sun, 2006). Each approach has its own advantages and disadvantages.

In this study, the spectral decomposition method is based on wavelet transform of the input seismic volume using Gabor-Morlet wavelet. Gabor-Morlet is a wavelet characterized by strong central peak with sidelobes decaying in amplitude. Convolution of this wavelet with seismic traces, results in filtering of underlying dominant frequency band while maintaining local relative frequency changes. The wavelet can be applied in two different modes viz. Frequency increment or Octave increment mode. In frequency increment mode, Gabor wavelet with equally spaced central frequency is convolved with the data. In case of Octave increment, Gabor-Morlet filters are designed with equally spaced central frequencies in octave-frequency domain, hence unequally spaced along a frequency axis. Another method of visualizing seismic data in different frequency ranges is generation of Tuning Cube where a number of flattened horizon slices each with different frequency contents, are derived for a particular horizon and stacked as one at top of another sequentially, to create a volume that can be scrolled through easily.

Spectral decomposition with wavelet transform is of great use to understand variation of stratigraphic thickness (Laughlin et al., 2003). Two stratigraphic features with difference in thickness may have different characteristic expressions in frequency domain e.g. the expression of a channel and overbank deposit will be different if viewed on RMS amplitude map with different frequency ranges. It is observed that thin beds are well visualized in high frequency ranges whereas thicker beds are seen better at low frequencies.

Seismic attribute (fusion):

Volume blending/fusion displays information of two or more attributes with interactive opacity control applied independently on each attribute to improve visibility and enhance discrete features or variations. In this process three spectrally decomposed volumes are assigned red, green and blue color. The nature of color at a point in the final image is determined by the values in individual frequency volume e.g. in this study the yellow color is formed for higher value of amplitude in 30Hz (red) & 20Hz (green). Features appearing dark are having low values in all frequency volumes.

Seismic facies Analysis:

Seismic facies classification is based on shape and character of the seismic waveform, which is often used for identifying facies distribution. Seismic waveform carries information about frequency, phase and amplitude. Any variations observed in these parameters are again interpretable results of lithology, porosity and fluid content. In this study we utilized unsupervised neural network based classification.

The Shape and character of seismic waveform identified in any time interval can be studied using pattern recognition techniques, and then displayed in map view, that can be interpreted in term of seismic facies variation within interval, which can be caused by lithologic variations and fluid content.

Unsupervised, neuron generated or user defined classes are generated from synthetic traces to best represent different trace shapes within the chosen interval. Classes are arranged in progression (assigned number to these neurons), which are examined to get the idea for shape of waveforms. Each trace in interval is iteratively compared with trained synthetic traces and those trace that have maximum correlation with a given synthetic trace are assigned to particular class.

Neural networks can be thought of multi-channel processing systems which attempt to learn and generalize a set of processing rules given a number of known inputs and optionally known outputs (Russell et. al., 2005).

The products from these three approaches were interpreted in an integrated way, to map depositional facies within the target interval in the Oligocene sequence of deep water Krishna-Godavari basin.

Work flow

Indicative work flow applied on this case study is given in Figure 2. The first step was to do detail interpretation of 3D PSTM seismic volume. As a part of interpretation several seismic horizons have been mapped (Figure 3) and their RMS amplitude maps are used for interpreting broad depositional systems in the area. Among several identified reservoir intervals the Oligocene sequence is chosen for current study as the first regional deepwater dispersal systems evolved in this time. The PSTM seismic volume is used as an input for spectral decomposition and three volumes named 10Hz, 20Hz and 30Hz are derived with corresponding centralized frequency of 10, 20 & 30 Hz. These three attribute volumes were assigned blue, green and red color respectively and blended together in volume fusion technique. These three volumes are also used to generate RMS amplitude maps for different frequency ranges along the surface with +/-4 ms window. Other than the above two approaches, the seismic facies analysis is also carried out on PSTM volume and on the three decomposed spectral volumes. 10 model traces defined as classes were first trained using the selected volumes and subsequently were propagated within the studied interval to generate seismic facies maps. As a QC of the map, the correlation between subsequent classes was verified in correlation window (Figure 4).

All the maps generated, using these three approaches, are analyzed to develop geological understanding and map depositional facies, in the Oligocene sequence.

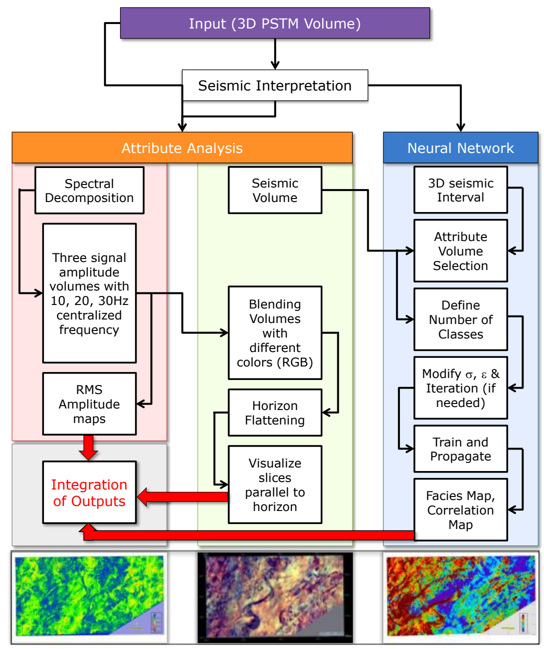

Figure 2: Work flow adapted for analysis.

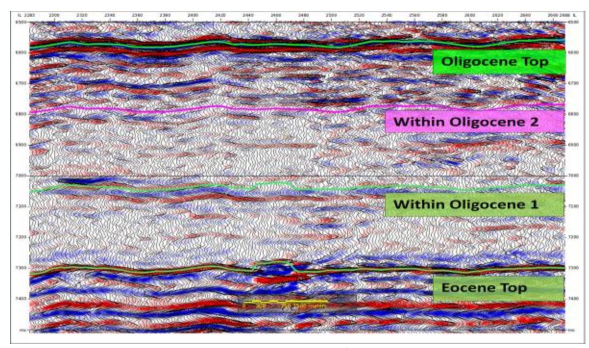

Figure 3: Seismic section illustrating reference horizons within Oligocene sequence.

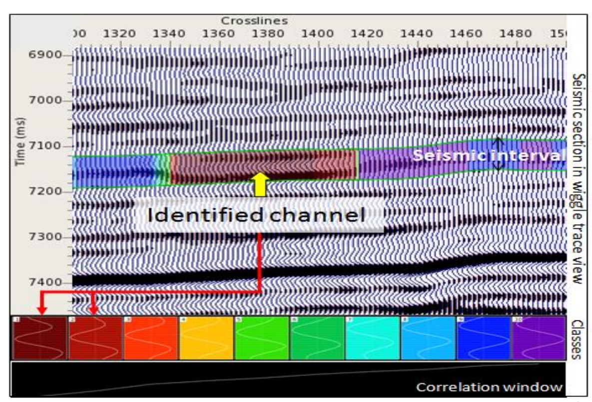

Figure 4: The seismic section showing 10 classes and similarity of seismic trace.

Results & Discussion

The Oligocene sequence is deposited by a southwesterly flowing channelized dispersal system which initiates from the lower part of the sequence and becomes prominent in the upper part. The channels are narrow, relatively straight to meandering in lower part (Figure 5), while in the upper parts in addition to these, broad, meandering channels become progressively dominant (Figure 6). In seismic sections, channel morphologies are easily identified due to truncations of seismic reflections. The reflections within channel fills are gently dipping to parallel, indicating steady energy conditions during deposition. Difference in amplitude and frequency are present between the channels and the surroundings. However in some cases, where the channels exist within single seismic events, they are best resolved on RMS amplitude maps, though in such cases sharp lateral variations in amplitude can be seen in seismic sections (Figure 3).

The narrow channels in the lower part that are commonly lateral accretions and meander scrolls are discerned in the higher frequencies. Lithological changes within the channels are resolved across all the frequency bands, with variation of the details resolved. RGB blending of these frequency volumes helps discern subtle variations in the depositional elements and facies (Figure 5e).

Seismic facies classification however is able to resolve most of the channels in the full bandwidth volume, though internal details are at times obscured. To illustrate the efficacy of the work flow, results of a typical interval within the sequence are presented (Figure 5), wherein a channel present within a single seismic cycle is resolved.

RMS amplitude map from the PSTM volume indicates a few weakly resolved channels flowing towards SW. Width of individual channels vary from more than 1.5km to <100m. A weakly resolved westerly flowing relatively straight channel is present in the central part (Fig. 5a, CH-A) and is interpreted to be mostly clay filled. This channel is visible in the PSTM, 10 & 20Hz (Fig. 5a, b & c) and in the facies classification (Fig. 5f), while its presence is well resolved in the 30Hz (Fig. 5d) and weakly resolved in its downstream part in the RGB blended slice (Fig. 5e).

A prominent moderately sinuous channel is present in the central part of the area (Fig. 5a, CH-B). In the upper reaches, this channel shows little contrast from the encasing lithology, while in the downstream parts, it shows lateral accretions and a high degree of contrast with the surrounding, indicating the possible presence of sandy lithologies in the downstream. These differences are prominently seen in the 30 Hz, RGB and facies slices (Figures 5 d, e & f), while they are subdued in the PSTM and absent in the 10 & 20Hz slices (Fig. 5a, b & d). This channel also develops levees (Fig. 5b & e), unlike other channels in the area which do not show well developed levees. The levees appear as broad moderate amplitude areas flanking the channel, which grade into low amplitudes away from the channel.

The low sinuosity narrow channel CH-C, flowing parallel and east of CH-B, has a low amplitude response and is distinct only in the 20Hz volume (Fig 5c), while in PSTM and other frequency volumes its response is subdued or absent. RGB blending also fails to resolve it in a major part, except for its central part. The facies slice however discerns the full length of this channel which has a distinct contrast with the surroundings. Due to the low amplitudes within it in all frequencies, it is interpreted to be clay filled.

A south-westerly flowing channel (CH-D) in western extremities of the area illustrates a case specific effectiveness of seismic facies over the frequency slicing and volume blending (Fig. 5f). This low sinuosity channel is distinct in the seismic facies map, though is either not resolved or patchily resolved in the PSTM, frequency slices and the RGB blending. The non resolution of this channel in these volumes could be possibly due to either its low thickness or due to its fill having the same composition as its immediate surroundings.

In the north central part of the area, a low sinuosity narrow channel is seen in the PSTM, 20 Hz and 30Hz volumes (CH-E, Fig. 5a, c & d). This channel shows a low amplitude response in these two volumes, and seismic facies slices. The channel has a low thickness, which could be a cause for its non-resolution in the lower frequencies.

The southeastern quadrant of the area appears to be free of channels in the PSTM, 10Hz and 30Hz slices (Fig. 5 a, b & d).

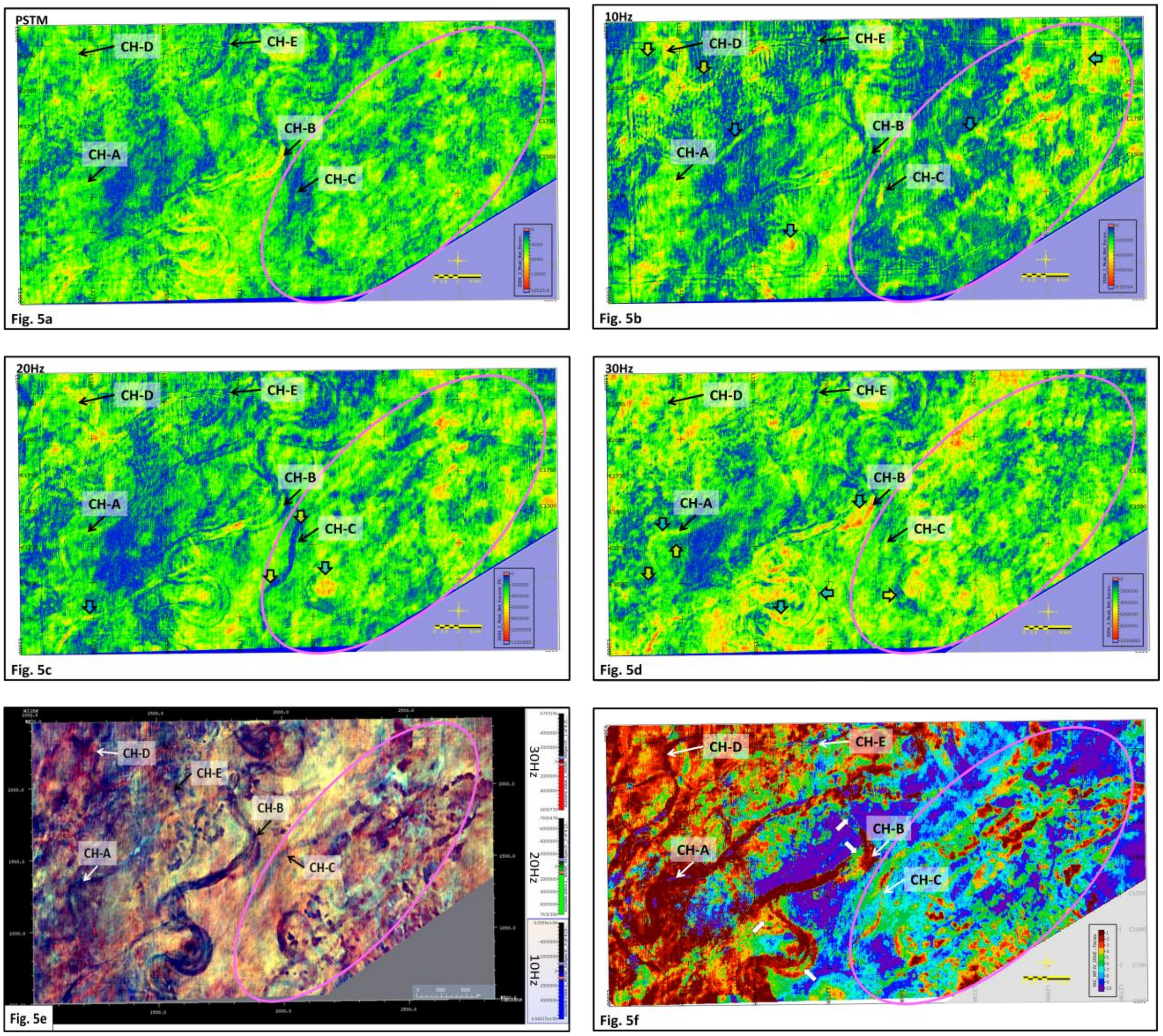

Figure 5: Slices along horizon 'Within Oligocene 1'
a) RMS amplitude, PSTM volume, a few meandering channels show a moderate to weak resolution.
b, c & d) RMS amplitude spectrally decomposed volumes with centralized frequency of 10, 20 & 30Hz.
e) RGB blending of 10, 20 & 30Hz volumes, flattened on 'Within Oligocene 1'.
f) Seismic facies map derived using neural network approach.

In the RGB blended while it is not resolved in the 10Hz, RGB blended and facies slices, presence of several relatively straight, southwesterly flowing channels (Fig. 5e & 4f) are seen. These channels show variable response along their course, indicating a variable fill within them.

RGB blending of frequency volumes utilizes additive blending and opacity control to selectively enhance subtle features. A particular set of opacity controls may enhance visibility of one band over others. It is well known that visibility of objects can be enhanced or reduced by varying the relative opacity and weightage preference to a particular input volume.

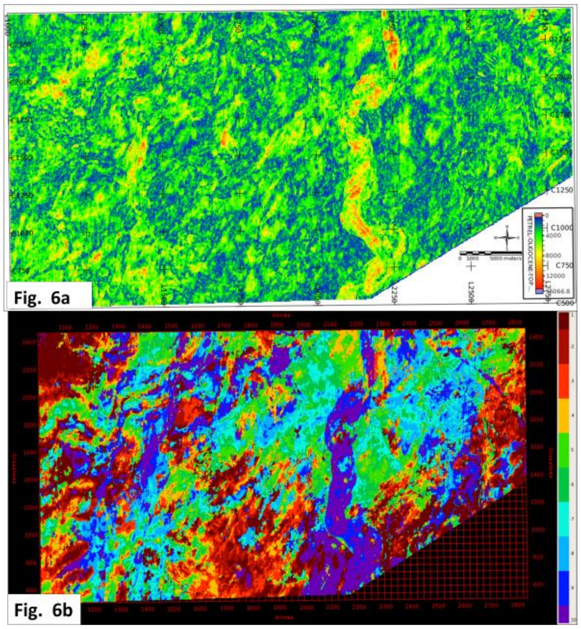

Figure 6: Slices along horizon 'Within Oligocene 2'.
a) RMS amplitude +/-4ms.
b) Seismic facies around horizon

The seismic facies on the other hand enhances the subtle differences in the neighboring seismic traces and hence is able to resolve these channels. The classes resolved can be subjective and usually an optimum is applied. Usage of blocky color scale usually enhances continuity of faces classes, while it may at times compromise on resolution.

In order to optimize resolution and recognition of subtle heterogeneities within depositional elements it is therefore advisable to use these techniques in combination, to achieve the best results.

Conclusions

Current case study led to bring out various depositional geometries through integration of different techniques that lead to better understanding of subsurface geological features which otherwise remain undetected. Integration of different methods and analyzing the subtle features seen on the response can be useful where well data are unavailable or sparse especially in frontier basins.

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Acknowledgments

Authors are thankful to the management of Bharat Petro Resources Limited, for providing facilities to carry out the work and consent to present and publish the same.