High-resolution mapping of Channel evolution of channel complex system on Slope regime using seismic spectral analysis: A case study in the offshore block of Krishna Godavari Basin, India.

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Keywords

Spectral decomposition, RGB (Red-Green-Blue) blending, Short Time Fourier Transformation, PaleoScan.

Abstract

Pliocene sands of Godavari clay formation were deposited as incised slope channels, constructional leveed channels, distributary channel complexes and distributary lobes. Sand dispersal in the form of slope channels and fans have already been imaged and proved by drilled wells in KG offshore. The Plio-Pliestocene prospects probed in study area were mainly for high amplitude anomalies on anticlinal structures/ fault closures over rollovers/toe thrusts. All those prospects were within upper Pliocene and the reservoir spreads interpreted from amplitude anomalies were of reasonably large areal extent and met with limited success. Noncommercial gas was discovered in few wells. The absence of commercial hydrocarbons in the larger prospects of upper Pliocene may be due to seal failure caused by Neo Tectonics (Pleistocene to Recent). However, thin meandering slope channels and their distal splays proved to be hydrocarbon bearing in lower Pliocene. Prediction of these depositional features, multi layered paleochannels and their lateral distribution and evolution is always a challenging task using conventional seismic interpretation due to the complex migratory interbedding within Tertiary sediments and subsequent sediment loading and collapse of the shelf edge, forming genetically linked growth fault and toe thrust pairs. In such complex geological conditions, this paper attempts to help in bring high resolution mapping of Channel evolution and it's lateral and vertical distribution in a slope channel fan complex system by using multi frequency slicing viz. spectral decomposition methods and RGB (Red-Green-Blue) blending of discrete frequencies. Understanding of vertical & lateral migration of these channel systems helps in delineating lateral extent of reservoir bodies in up dip and down dip along with effective mapping of all existing paleochannels. This might open a possibility of a new prospective reservoir horizon and identifying the adequate reservoir volume which helps in field development planning and reduces exploration risk in the Godavari clay Formation.

Introduction

Godavari clay formation of Pliocene-Pleistocene age of the thick Tertiary passive margin system has been the primary focus of exploration activities in the present study area of KG –Offshore block. Commence success was brought by the discovery of gas in Upper Pliocene-Pleistocene sands of well A. however the production rates were non-commercial and made insignificant contribution in improving the reserve base. Sands of this have mostly been water bearing where as thin meandering channel deposits of lower Pliocene have yielded hydrocarbons. The lower Pliocene meandering channel mouth bar complexes are more prolific and have given promising results. Most of these reservoirs are characterized by high amplitude anomalies. However, wells drilled on the basis of amplitude anomalies either turned out be dry or thin reservoir sand, only few wells turned out be thick commercial reservoirs.

Due to ambiguity in amplitude anomalies, it is not always possible to find out the geometry and distribution of these sand bodies based on the conventional seismic interpretation. Complex seismic anomalies are to be decoded so that reservoir-non reservoir ambiguity can be solved to an extent. This paper discusses seismic frequency attributes and their adequacy in seismic geomorphology study of Godavari clay formation of tertiary sediments. Seismic reflections are commonly composite one with reflections from several closely spaced interface caused by the individual frequencies present in the seismic signal bandwidth. Unless the component reflections are separated out, it is hard to define the geometry and lateral distribution of thin bed from a seismic data (*Nanda, N.C., 2016*). Spectral decomposition is a segregation technique in frequency domain. Frequency-stripping to individual frequencies results in enhancement of seismic resolution, vertically as well as laterally. It provides better resolution of bed thickness and lateral resolution superior to conventional amplitude horizon slice. Spectral decomposition reveals the thin bed geology with stratal details of the facies such as channel, levee, point bars and which were obscured or totally missed in normal vertical reflection section. The Spectral Decomposition module in Paleoscan software allows to create seismic trace-based attributes in order to better highlight geological features like channels, fault. The main purpose of this tool is to decompose the seismic signal into different energies corresponding to each frequency in the volume in order to create a spectrogram. By analyzing the spectrogram, it is possible to select several remarkable frequencies corresponding to geological targets. In combination with Horizon Stack and RGB Blending (*Haris, A., et al., 2017*), this tool can greatly improve the detection of specific geological formations based on the frequency imaging. It is important that lateral and vertical migration of the channel be precisely mapped to decide optimal drilling locations and proper field development.

This tertiary gas field of KG offshore block basin has been puzzling because of these sands of limited extent confined within thick Godavari clay. This high resolution mapping of paleochannels might reduce the geological uncertainty and aids the placement of exploration and development wells in Godavari clay Formation.

Geology

The study area falls within the KG-Offshore block, covering an area of 1193 sq.km is situated off the Coast of Godavari Rivers Vashista and Vainateyam in the bathymetry range of 250m to 1250m.Krishna Godavari Basin is a typical passive rift margin basin characterized by polycyclic evolution history which witnessed its first marine transgression during Albian- Aptian time. During Late Cretaceous to Palaeocene time, along with the onset of passive margin set up, southeast tilt of the basin was developed resulting in major marine transgression and onset of the primary fluvial pathways (Godavari and Krishna) and the two present day delta systems were established during early Miocene time (*Gupta, S. K., 2006*). The basic reservoir distribution of shelfal domain was mid-late Miocene coastal plain to shore face sands and present day slope domain is Plio-Pleistocene slope derived channel deposits and occasional incised slope channel sands. The primary targets for exploration in this area are Miocene to Plio-Pleistocene submarine fan and channel levee complexes. The sands are sourced from Godavari River system and deposited on the lower slope. No major tectonic element is observed in the study area.

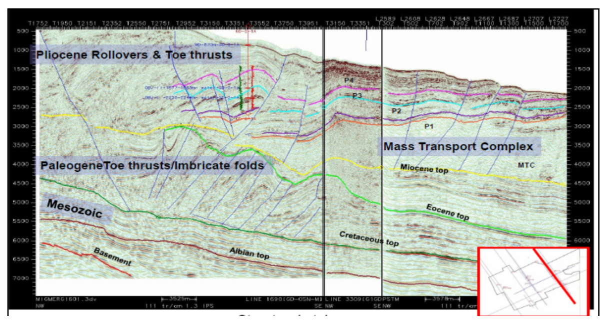

Figure 1: Dip line showing structural Style in the Study area

Study area is characterized by Miocene and older imbricate folds/ Toe thrust overlain by MTC unit followed by Pliocene growth related rollover anticlines and Toe thrusts (Fig 1). The Regional Time structure map at Base Pliocene (Fig 2) shows the dominant structures in this part of the basin are a major north-east-trending down-to-basin growth faults, the associated large A, B, C and D low-side rollover trend, and the genetically related younger toe thrust complex in the eastern part and relatively more faulted study area in the west. An anticlinal structure to the east of study between two major cross trends, one to the west of A structure and the other to the east of E structure, is also observed which turned out to be failure. The Pliocene listric faults generally have a NNE-SSW trend and typically sole out in the shales below. Stratigraphic trapping is also likely to be important, with traps formed by up dip pinch-out of the linear slope fan channel complexes.

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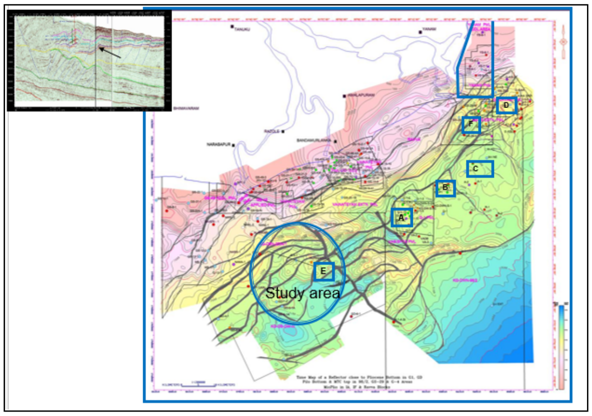

Figure 2: The Regional Time structure map at Base Pliocene shows the dominant structures.

Adapted Methodology

Spectral decomposition unravels the seismic signal into its constituent frequencies allowing delineating subtle geological features tuned at a specific frequency. Spectral content of the recorded seismic wavelet is dependent on acoustic impedance variations along its path. Spectral decomposition (*Partyka, et al., 1999*), which employs the use of frequency slices of seismic data to determine temporal depositional thickness of lateral geologic discontinuities, remains a very popular and effective means of using a frequency attribute for exploration, especially sand channel delineation. Decoding this spatial variation of spectral content can yield a detail comprehension of subsurface geological variations. The main purpose is to decompose the seismic signal into different energies corresponding to each frequency in the volume in order to create a spectrogram. By analyzing the spectrogram, it is possible to select several remarkable frequencies to geological targets.

Several methods of spectral decomposition are available, however extraction of frequencies has been done though Short Time Fourier Transformation in Paleoscan software, a 3D seismic interpretation software that follows the below steps (Fig 3).

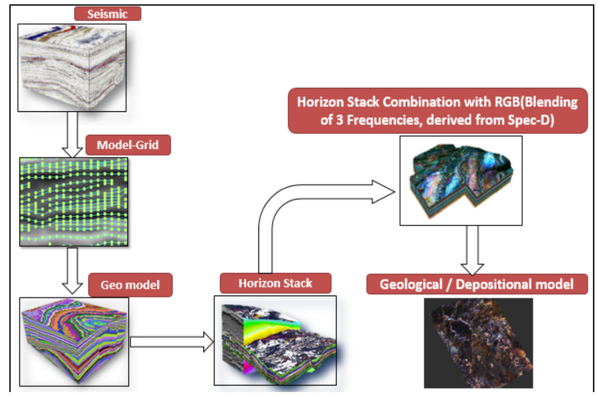

Figure 3: PlaeoScan™ Workflow to achieve final out-put

Model Grid has been generated, by merging seismic points according to the similarity of the wavelet and their relative distance of seismic points of input seismic volume within the vertical window of 3D by merging seismic points. This process automatically tracks every horizon within the input seismic volume to constrain a grid, where a relative geological time is computed for every point. The second step will be the generation of the Relative Geological Time Model from the Model-Grid, Where a relative geological age is assigned to each pixel of the input seismic volume. Once Model is computed, an unlimited number of horizons can be derived from the 3D Geo-Model. This set of horizons is called Horizon stack by defining top and bottom boundaries of the Horizon Stack. The Horizon Stack enables an interactive strata-slicing through the seismic volume as well as through attributes volumes like Spectral Decomposition. Identified desirable three discrete frequencies generated by Spectral decomposition process will be blended through RGB color blending where these three frequencies are represented by the red, green and blue elements into the 3D color volume. The Horizon stack was generated for channel sands characterized by bright amplitude seismic anomaly by defining top and bottom boundaries of the anomaly and combined with RGB Blending in order to improve the detection of meandering channel.

Results and discussions

A zone of interest was selected containing the reservoir sand by high seismic amplitude anomaly incased in transparent seismic section (Fig 4).

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Spectrogram generated against the zone of interest that helped to identify tunning frequencies 14Hz,27Hz & 46Hz corresponding to high seismic amplitude anomaly (Fig 5).Spectral peak amplitude volumes corresponding to frequency viz. 14Hz , 27Hz , 46Hz were extracted using Short Time Fourier Transform in Paleoscan software .

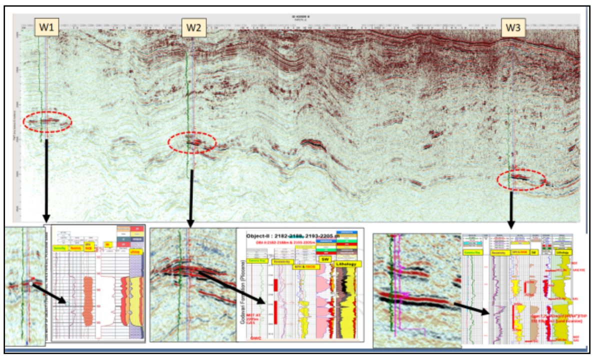

Figure 4: Seismic section along the Wells W1,W2,W3 showing the Channel sands are characterized by isolated high amplitude anomalies and corresponding log motifs.

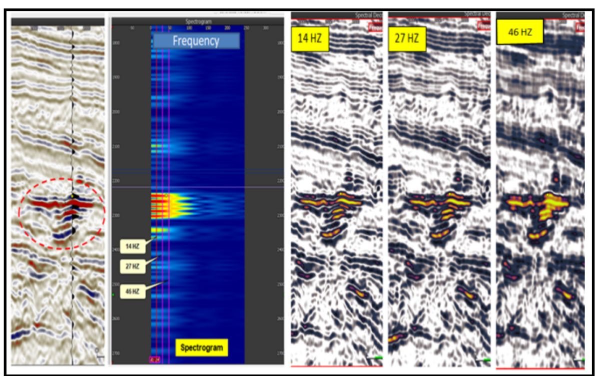

Figure 5: Analysis of Spectrogram against the seismic anomaly (corresponding to Channel sands) and Spectral peak amplitude volumes corresponding to frequency viz. 14Hz , 27Hz , 46Hz.

Horizon stack of 10 horizons was generated by covering vertical window of high seismic amplitude anomaly that corresponds to reservoir sands (Fig 6).

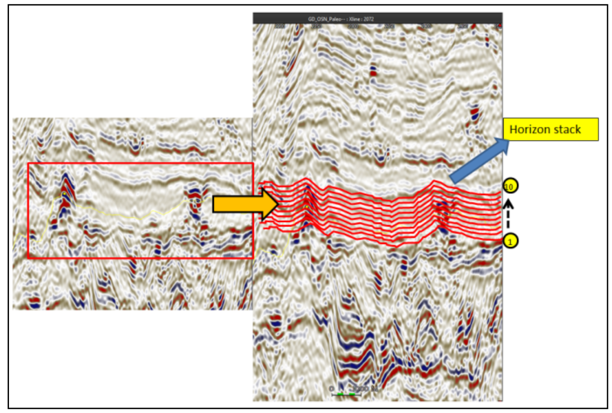

Figure 6: Horizon stack of 10 horizon slices covering the vertical window of Channel features.

10 Horizon slices were prepared, In combination with Horizon Stack and RGB blending of selected frequencies 14Hz, 27Hz & 46Hz (Fig 7 , Fig 8)).

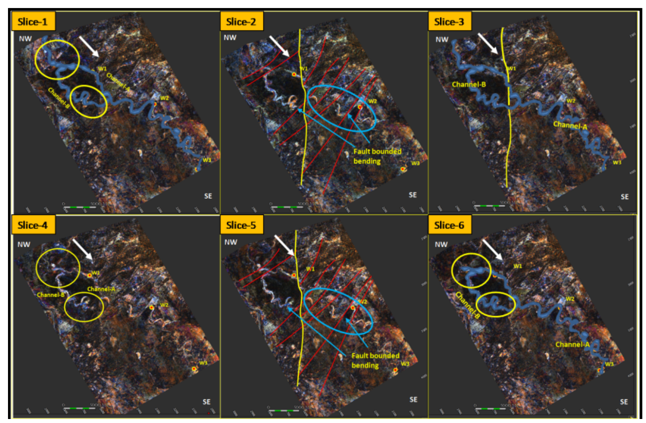

Figure 7: Horizon slices from 1 to 6 with RGB blending frequencies.

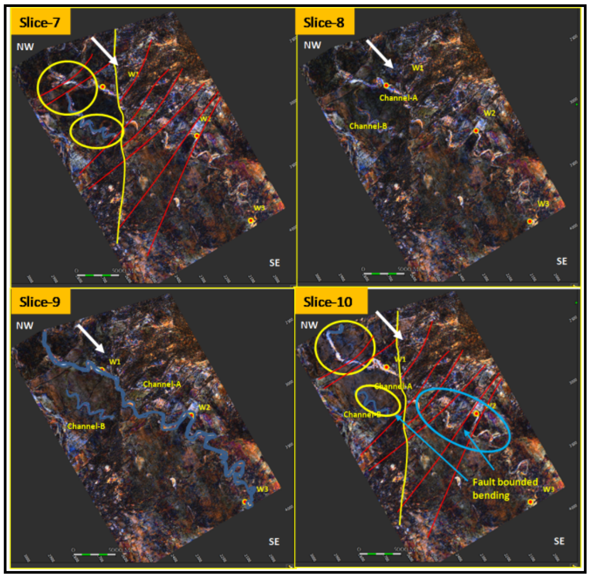

Figure 8: Horizon slices from 7 to 10 with RGB blending frequencies.

From Horizon stack slices, it is clearly visible that Channel A and Channel B are flowing from Northwest to Southeast direction. The overall slope of the terrain is from NW-SE and a major fault is dissecting the area from North to South (Yellow line) and parallel smaller cross fault network (probably polygonal faults) existing in NE-SW direction. Both the channels are coalescing/sharing same catchment at upstream. Well 1, 2, 3 are drilled in axis of channel A. along the N-S fault trend, through its fault plane, Channel A is changing its flow direction from NW-SE to N-S and then NW-SE. Whereas Channel B is changing its flow direction from NW-SE to S-N and merging with Channel A. Along the cross faults, Channel A is taking sharp bends i.e. forced meanders. Along the cross faults, Channel A is taking sharp bends i.e. forced meanders. From Horizon slice 1-6, it is understood that, initially the channel B is a strong channel which was bringing more water and coarse sediment and As time passes from horizon slice 7-10, Channel A is pirating the water from Channel B at headward side and making channel B a weak channel and devoid of sediment thus making channel B, a died stream within no time.

Such channels though lived relatively less time and limited to small areal extent, consists of best reservoir characteristics towards upstream. The sinuous bends bounded by faults on both sides are also best areas for hydrocarbon exploration. The following figures show the corroboration of channel thickness at the wells.

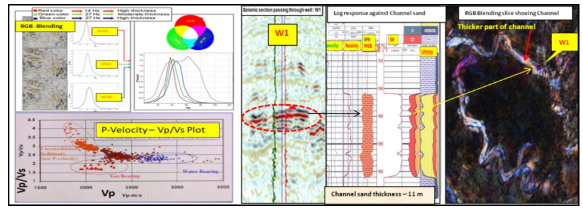

Figure 9: Well, W1 falls on the blue-colored part of the channel, which implies an amplitude anomaly that corresponds to the channel sand of W1, which is tuned to a 46 Hz frequency. With tuning frequency 46 Hz and interval velocity 2100 m/s, ƛ/4 = 11 m thickness (clean sand in the proximal part of the channel).

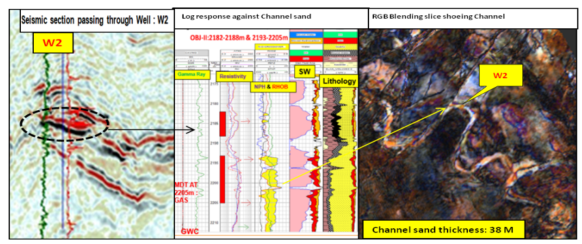

Figure 10: Well, W2 falls on the red-colored part of the channel, which implies an amplitude anomaly that corresponds to the channel sand of W2, which is tuned to a 14 Hz frequency. With a tuning frequency of 14 Hz and an interval velocity of 2150 m/s, ƛ/4 = 38 m thickness (the lower part is clean sand and the upper part is shaly sand).

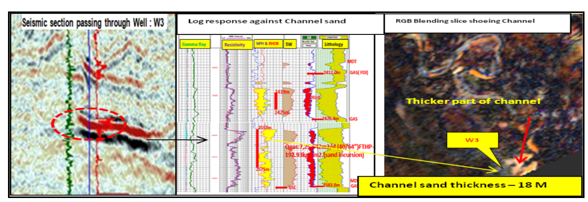

Figure 11: Well, W3 falls on the green-colored part of the channel, which implies an amplitude anomaly corresponding to the channel sand of W3, which is tuned to a 27 Hz frequency. With a tuning frequency of 27 Hz and an interval velocity of 2180 m/s, ƛ/4 =18 m thickness(Shaly sand ,Edge of the Fan body).

Conclusions

This paper shows an understanding of one of the seismic trace-based attributes i.e., frequency in order to better highlight geological features like channels, and faults. Spectral decomposition and RGB blending of discrete frequencies in combination with Horizon Stack have enabled the detection of Channel evolution and its lateral and vertical distribution in a

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slope channel fan complex system. This high-resolution mapping of paleochannels might reduce the geological uncertainty and aids the placement of exploration and development wells in the Godavari Clay Formation.

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Model Grid, Geo model and Horizon stack workflows in PaleoScan™ software.

Well completion reports and unpublished ONGC internal reports

Acknowledgment

The authors are grateful to ONGC limited for giving the opportunity to carry out this study & giving permission to submit. Authors express sincere gratitude to Basin managers, WOB and KG-PG Basin for the encouraging scientific environment and encouragement.