



Identification of fine depositional patterns and subtle stratigraphic plays in fluvio-deltaic depositional environment of Kalol Formation: A study from Cambay Basin

Umang Sundriyal*, Barnali Tokhi, Sudhir Chauhan, Manoj Kumar Maurya, Arnab Nag, BPRL, Mumbai
umang.sundriyal@bharatpetroresources.in

Keywords

Spectral Decomposition, Kalol Formation, Depositional Environment, Stratigraphic Features, Channels etc.

Abstract

Seismic Reprocessing of the vintage data has brought out finer depositional elements present in the Kalol Formation. Utilization of spectrally decomposed bands, Seismic Pre/Post Stack Inversion, RMS Amplitudes and various other tools for unraveling the Eocene depositional system in the Cambay Basin basin in India, aided in detailed mapping of various depositional elements and subtle facies variations within them. Through mapping and sequential slicing of the Eocene sequence a full depositional cycle of Kalol formation is interpreted which helped in identifying subtle stratigraphic traps.

Introduction

Present study deals with Kalol formation deposited in Cambay basin (Generalized stratigraphy of Cambay basin is given in Fig-1). The study area is located near the Eastern Basin Margin, within the Ahmedabad-Mehsana block of Cambay Basin (Fig.-2). The post rift succession in the Ahmedabad area starts with the deposition of deltaic – tidal-estuarine sediments of the Kalol formation followed by the Late Eocene widespread transgression depositing Tarapur Shale (Kumar et al, 2008).

In the study area, Kalol Formation was deposited in a typical fluvial-deltaic environment, where depositional features like fluvial channels, point bars, crevasse Splay and possible Shoals are observed. These fine depositional elements were not observed on the legacy 3D seismic data. Reprocessing was carried out for merging of three different vintages of 3D seismic data sets and subsequent processing for PSTM and PSDM. Reprocessing of the data significantly improved the frequency content, enhanced the discontinuities, normalized the amplitudes, thereby revealing the subtle stratigraphic features which were not visible in the legacy data.

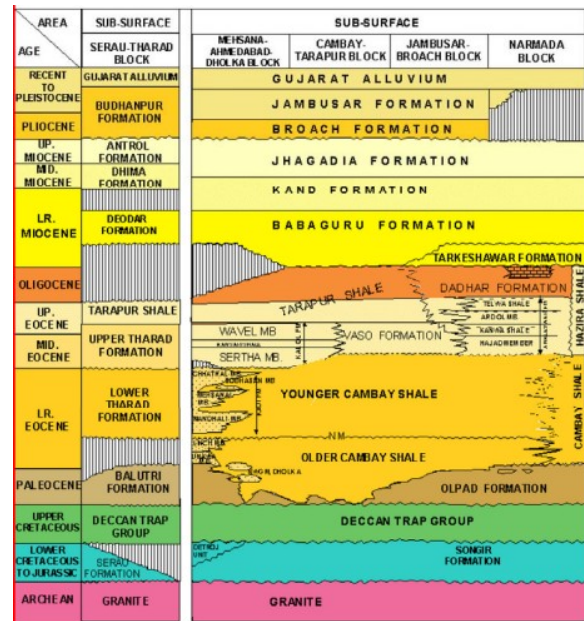


Figure 1: Stratigraphy of Cambay Basin (modified after Chandra and Chowdhary,1969).

Methods such as spectral decomposition, seismic pre/post stack inversion, horizon slicing, amplitude extraction etc. were used for identification of depositional elements. In this study, Horizons and/or slices of each individual Kalol units were interpreted to observe the evolution of depositional environment throughout the Kalol formation and thereby identifying subtle stratigraphic traps, as possible exploratory targets.

Theory and Method

Study area covers 170 SKM with ~100 % of 3D seismic coverage and six drilled wells. 3D seismic acquisition was done in three different vintages with similar acquisition parameters. However, all the data sets were different in terms of phase, frequency and

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S/N ratio. These three surveys were merged to achieve a unified geometry and reprocessed

elements and features. Significant results from this analysis are discussed herein.

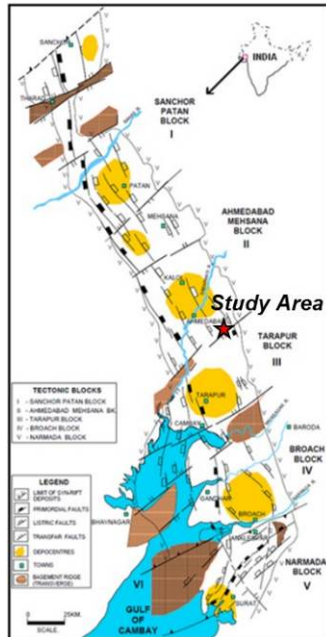


Figure 2: Location of the study area marked with red star.

subsequently for PSTM and PSDM processing. Reprocessing mitigated issues related to variable mis-ties along the legacy survey boundaries, improved S/N ratio and frequency content, enhanced fault imaging and normalized amplitude values (Fig.-3 A). While frequency content of the legacy seismic data ranges from 12 Hz to around 55 Hz, reprocessed seismic data shows presence of frequencies as high as 70 Hz (Fig. 3-B). Flat tail in the frequency spectra, towards the high frequency part is associated with deeper basement reflections.

Seismic interpretation was carried out and horizons were mapped at each unit of Kalol formation present in the study area. Further, Horizon and Proportional slices were generated at places where thin Kalol units were below the seismic resolution. Several attributes, viz. Amplitude, Edge Attributes, Spectral Decomposition, Seismic Pre/Post Stack Inversion, Seismic facies etc. have been used to bring out structural and depositional features in the seismic data, especially for the Kalol Formation. Amongst these attributes, Amplitude, Spectral Decomposition and Pre/Post Stack Inversion were found to be best suited for bringing out very fine scale depositional

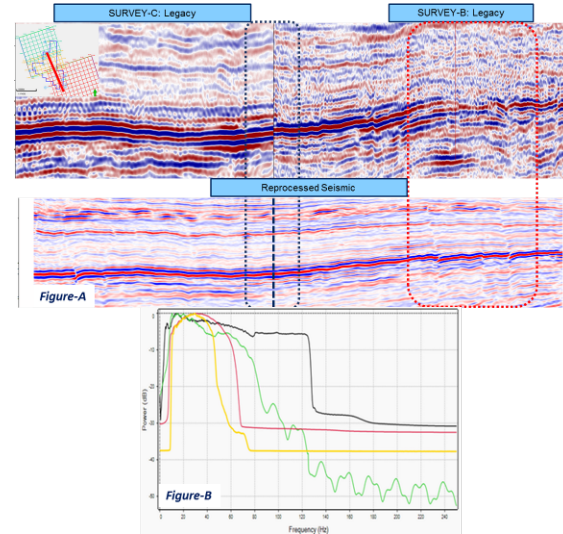


Figure 3: A) Comparison of Legacy 3D seismic Data sets with merged reprocessed data. Reprocessed data looks better in terms of the S/N ratio, frequency content, corrected variable mis-ties along the survey boundary (blue rectangle) and remarkable improvement in fault imaging (red rectangle). B) Comparison of Frequency spectra of legacy 3D seismic Data (in yellow, red and green) with the Merged and Reprocessed 3D Seismic data (Black).

RMS amplitudes extracted from Spectrally decomposed volumes along horizon slice generated +/- 10ms for the K-IX top (Fig. 4), illustrate the resolution of different depositional elements in the selected 10Hz increment bands for the PSTM. These maps are analyzed, as a representative of the system, on 30, 40, 50 and 60 Hz spectrally decomposed volumes (Figure-3). K-IX top has a dominant frequency around 45 Hz. The meandering channel feature and its individual components are prominent in high frequency band (60 Hz), which has brought out minor details of the thin depositional elements. The amplitude analysis reveals fine stratigraphic details and depositional elements at the mapped horizons which were not visible in the vintage seismic volumes. The RMS Amplitude maps at different frequency bands (Figure-4) are a good example for illustrating the efficacy of the re-processing and merging effort.



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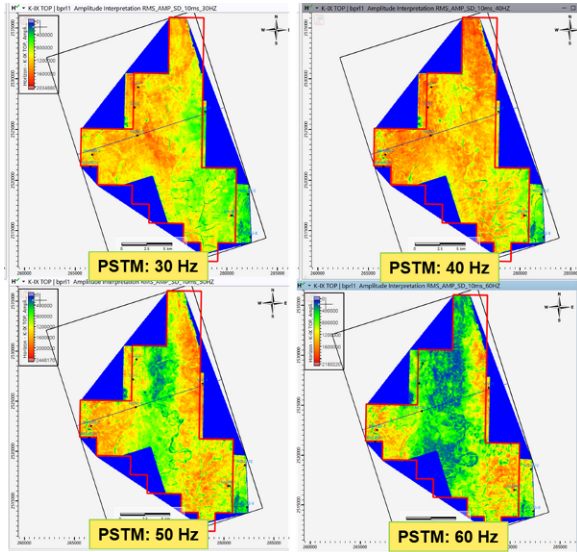


Figure 4: Spectral Decomposition at different frequency bands (30 Hz, 40 Hz, 50 Hz and 60 Hz RMS Amplitudes +/- 10Hz). Most of the depositional features are seen at higher frequency bands.

Amplitude analysis, with help of RMS Amplitude (+/- 5ms around each horizon) and Pre/Post Stack Inversion have been carried out for each of the mapped horizons on PSTM. Additional RMS amplitude analysis has also been done by proportionate slicing in-between the mapped horizons.

Chhatral: RMS Amplitude maps at Chhatral level (Fig.-5) are nondiagnostic of any depositional features likely due to deposition in a transgressive marine environment. The channel like feature seen in these maps is interpreted to be an interbed multiple of a channel incision at top of K-X.

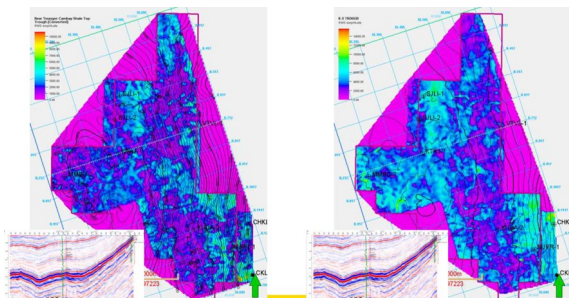


Figure 5: RMS Amplitude Map (+/- 5 ms interval) at the Base (left figure) and Top of Chhatral.

K-X: Acoustic Impedance and RMS Amplitude Maps of Proportionate slices between Peak within K-

X and Younger Cambay Shale (YCS) Top show the presence of a channel like feature in the area south of Well W-3 (Fig.-6). The interbed multiple of channel incision at top of K-X is weak at this level.

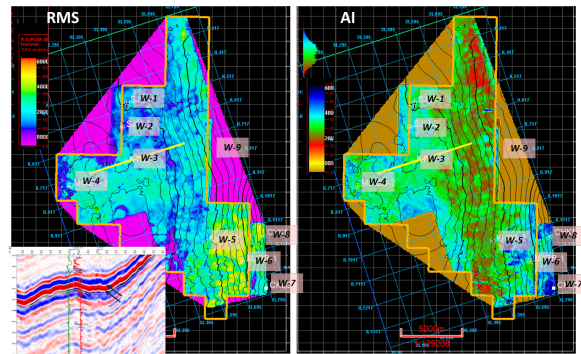


Figure 6: RMS and Acoustic Impedance: Proportionate Slice between YCS Top to PEAK (Doublet, Upper) within K-X.

Interface of K-IX and K-X: The slice at the Z crossing between the K-IX peak (corresponding with K-IX clastics) and the K-X top trough shows the presence of a SE-NW trending meandering shoe-string channel system (Fig.-7). In the southeastern parts of the block two channels are seen merging, one flowing roughly N-S (Channel System-A, CS-A) parallel to the basin axis and one flowing NNW-SSE (Channel System-B, CS-B). The channel systems show variable sinuosity along the channels probably due to changes in paleoslope along the channel profile. The NNW-SSE CS-B is interpreted to have low thickness as it is only resolvable at higher tuning frequencies and observed only in the horizon slices. The channel CS-B is interpreted to be a crevasse splay formed during avulsion of the CS-A.

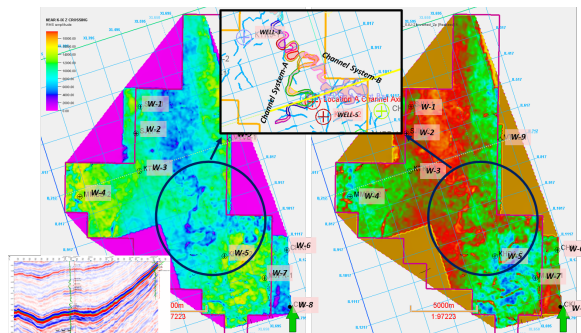


Figure 7: RMS Amplitude Map (left) and Acoustic Impedance (Right) at the interface of K-IX and K-X.

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The Channel System-A is very well visible in the seismic sections with change in amplitude, presence of channel cuts. Detailed analysis reveals that this channel is at the base of the K-IX clastic interval, seismically resolved near the 'zero' crossing between the K-IX peak and K-X coal trough (Fig.-8). At this level, this channel has low amplitude in comparison with the surrounding sediments.

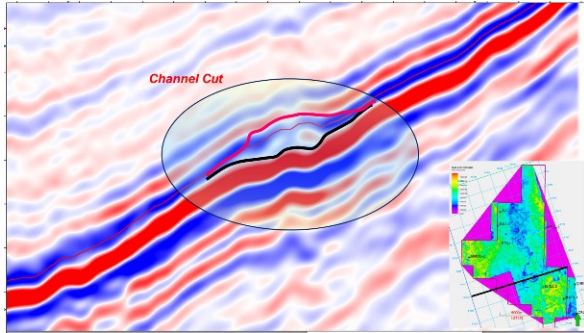


Figure 8: Seismic Section Passing through the Channel Incision shows a positive relief (Concave upward) indicative of presence of coarser clastics within the channel fill.

P Impedance, derived from the Post Stack Inversion also indicates, lowering of Impedance in the Channel System-A, as compared to its laterally equivalent facies (Figure-7). RMS attribute map indicates that the fill in channel is different than background lithology. Considering the facts that the higher amplitudes in the surroundings may be due to the high impedance contrast between the overlying shales and the coal / carbonaceous shale present within K-IX/K-X, the lower amplitude within the channel with a relatively much lower impedance contrast and positive relief at the top are indicative to presence of coarser clastics. Presently it is interpreted as a channel incised onto the K-X coal. Point bar associated with this channel observed as accretion surfaces in the RMS slice, which may contain reservoir quality sands, therefore can be worth-while location for exploratory drilling.

It is logical to expect incision by basal units of K-IX, considering the fact that after the Highstand represented by the K-X top coal, there is a period of lowstand regression separating the longer duration transgressive phase represented by the fining up clastic intervals within K-IX (Fig.-9).

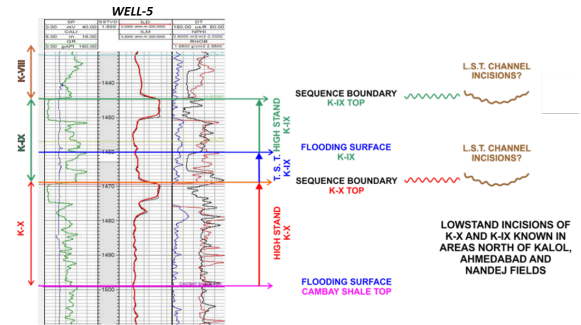


Figure 9: Log Motif of one of the representative well showing identified sequences. After the Highstand represented by the K-X top coal, there is a period of lowstand regression separating the longer duration transgressive phase represented by the fining up clastic intervals within K-IX.

K-IX: The slices of the K-IX top reveal the presence of numerous thin depositional features (Fig.-10). Channel systems with wider meandering scrolls are prominent at this level indicating very gentle paleo slope during deposition. These channel incisions are interpreted to be developed during the lowstand phase with a sequence boundary at its base and on top of K-IX coal (Fig.-9).

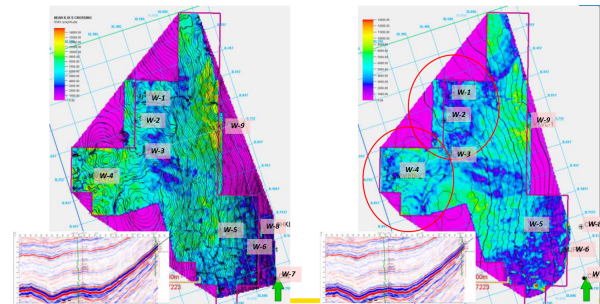


Figure 10: RMS Amplitude at S Crossing (Left), K-IX Trough/K-VIII Peak and at (Right) K-IX Trough.

K-VIII: RMS amplitude slices from K-VIII are shown in Fig.-11. North to SW and westward flowing meandering channels are prominent within K-VIII level. The meandering scrolls are observed with relatively bright amplitudes at places. Drilled wells suggest the presence of carbonaceous silts/shales in this interval. A prominent fan-like feature seen in the central part of the study area is interpreted as a washover fan/delta deposited during high tides.

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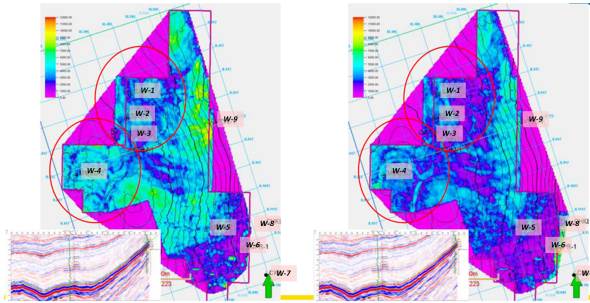


Figure 11: RMS Amplitude at Z Crossing (Left), K-IX Trough and at (Right) Peak within K-VIII.

K-VI+VII: Horizon slices within this interval show presence of NNW-SSE trending straight brighter amplitude bands. (Fig.-12) These are interpreted to be possible shoals parallel to the basin margin.

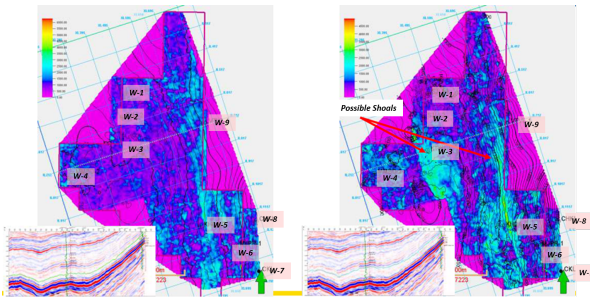


Figure 12: RMS Amplitude at Trough within K-VI+VII (Left) and at Near K-VI+VII Top Trough (Right).

Kansari: Horizon slice near Kansari top (Fig.-13) shows the presence of a NNW-SSE trending bright amplitude feature with a sharp western boundary. This is also interpreted to be shoal / paleo-strand line. The feature is penetrated in W-3 and shows the presence of relatively higher density streaks which may correspond to maximum flooding surface near Kansari top (Bhadu et. al, 2012).

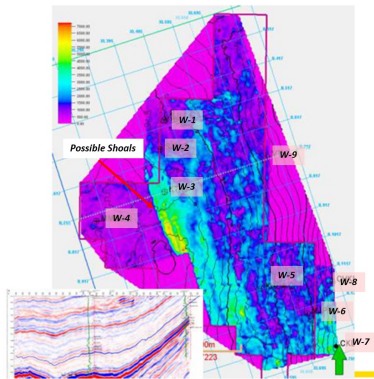


Figure 13: RMS Amplitude Near Kansari Top.

K-V: The slice within K-V (peak) shows the presence of a WSW flowing channel, possibly emerging from the basin margin. Horizon slice in the overlying trough reveals the presence of a low sinuosity meandering NNW_SSE trending shoe-string channel (Fig. 14). These channels at the base of Wavel member have relatively brighter amplitude than the surroundings. Considering that the surrounding lithology is mainly shaly, these channels are likely to contain reservoir facies.

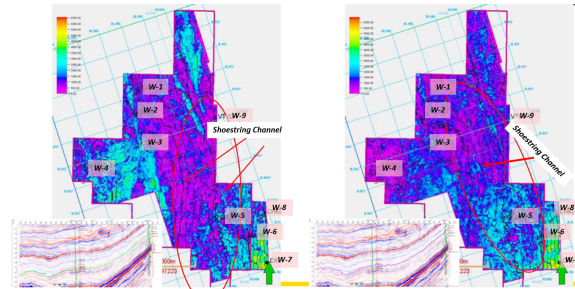


Figure 14: RMS Amplitude Near K-V Peak (Left) and Trough (Right).

K-III+IV: The seismic data at K-III+IV interval is apparently with low frequency and amplitudes, implying low impedance contrasts. This is corroborated by the drilled wells encountering finely interlayered sands and shales. Horizon slices (Fig.-15) also reflects the same, which show either uniform very low amplitude distribution or patchy amplitudes with no distinct patterns.

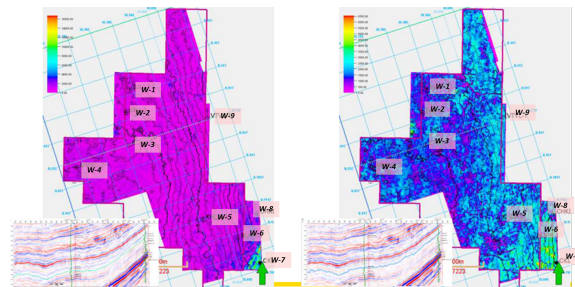


Figure 15: RMS Amplitude within K-III-IV Peak (Left) and Near K-III-IV Top (Right).

Kalol Top: Several sets of channels are seen on the slices near Kalol Top (Figure 16 and 17). The oldest system appears to be trending NNW-SSE (Figure-16), cut across by a ENE-WSW trending system. Both these display relatively high sinuosity and are

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brighter than the surroundings. Higher up a low sinuosity ENE-WSW, low amplitude channel is seen (Fig.-17).

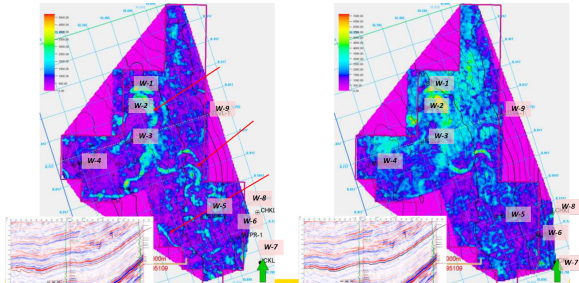


Figure 16: RMS Amplitude at Trough below Kalol Top (Left) and Peak below Kalol Top (Right).

These channels are related to the sequence boundary at the top of Kalol Formation marking the end of highstand phase. The channel sets in directions perpendicular and parallel to the basin margin would represent rapid changes in the dispersal system, probably dictated by base level changes or provenance dynamics. The system parallel to the NE-SW basin margin would represent the long term axial dispersal system, while the system perpendicular to the basin margin would represent shorter term episodic influx from across the basin margin.

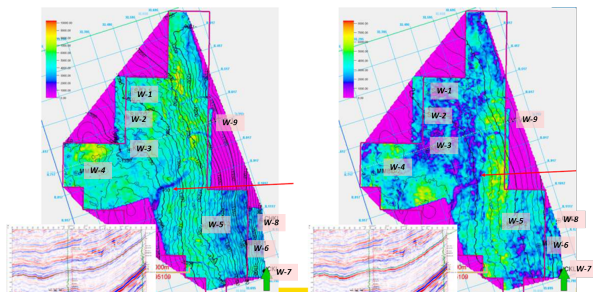


Figure 17: RMS Amplitude at Kalol Top Trough (Left) and Peak above Kalol Top (Right).

Petroleum System Analysis:

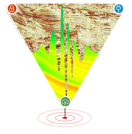
Cambay Basin stratigraphy is comprised of elements of active petroleum system, which are proven in nearby discovered fields of the study area. The Cambay shale is a regional source rock deposited during Middle Eocene-Lower Paleocene and is comprised of Type II/III kerogen. The study area has a structural low in the southwestern part, which could be a kitchen area for the fields nearby. The critical period of hydrocarbon generation was during Late

Miocene (Sarma, 2012). The overlying Kalol Formation is comprised of eleven pay sands named as K-IX to K-I from bottom to top (Mehrotra et al 1980 and Das et al, 2011). The K-I to K-V belong to Wavel Member, K-VI and K-VII to Kansari shale and K-VII to K-XI to Sertha Member of Middle to Late Eocene age (Pandey et al., 1993). Although K IX-X are the key producers in the nearby fields, hydrocarbon discoveries are also reported in the shallower K-VIII, K-VII, K-VI and K-III-IV etc. intervals.

Within the study area, the channel systems of K-X & K-IX which are structurally located east of the basin margin slope can form stratigraphic traps. Based on the analysis of the seismic amplitude and acoustic impedance volumes, the fill within the channels, point bars and distal splays are interpreted to have reservoir facies/sands. The overlying coal and silt facies within K-X and K-IX form the top seal whereas lateral change in facies could act as lateral seal within the traps. The shoal facies within Kansari Member could develop stratigraphic traps however reservoir quality and presence of lateral seal are key risks. Although no distinct depositional feature has been identified at K-III-IV level, thin sands could pinch out over the highs in the east and form stratigraphic traps. There are numerous channels observed at the Kalol top which are overlain by transgressive Tarapur shale which form a regional seal for Kalol Formation, hence could also form stratigraphic traps. These kinds of stratigraphic could be considered as potential candidates for exploration.

Conclusions

Attribute analysis has revealed the presence of fine stratigraphic and depositional details in the study area. The depositional elements detected, viz. channels, point bars and offshore shoals can be good elements for stratigraphic plays. While the wells earlier drilled in the block, were mostly on structural prospects and none of them have penetrated the depositional elements presently identified. Analysis of the fine depositional patterns associated with these channels, their compaction relief and relative amplitudes help to determine whether they contain reservoir prone clastic facies or non-reservoir fill.



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