ANATOMY OF A SUBMARINE CHANNEL IN ERUMBUR CANYON, CAUVERY BASIN FROM 3-D SEISMIC DATA

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Keywords

Submarine Channel, Ariyalur-Pondicherry Sub-basin, Cauvery Basin, Point Bar, Kamalapuram Formation

Summary

Deep water channels associated with submarine fans have been recognized and explored in several basins around the world as they host commercial volumes of hydrocarbons. The present work describes the geometry of Erumbur submarine channel in Ariyalur-Pondicherry sub-basin of Cauvery Basin, southeast India to assess its hydrocarbon prospectivity. The erosional activity at K/T (Cretaceous-Tertiary) boundary has shaped canyons in this sub-basin, viz., Radhapuram and Erumbur, which were revealed in high resolution 3D seismic data. Several attributes were studied for better understanding of the architecture of Paleocene Kamalapuram canyon fill sediments. The RMS amplitude attribute between K/T and Paleocene reveals that the Erumbur channel in the east was a sinusoidal meandering channel; while in the western Radhapuram Canyon, the channel activity was dormant. The Erumbur Channel is a mature meander complex and displays an abandoned point bar adjacent to it. These features are corroborated by spectral decomposition and sweetness attributes. The present study has brought out two high-amplitude isolated geobodies viz., an abandoned point bar and a mid-channel geobody having strati-structural entrapment conditions. Few drilled wells in this channel confirm the presence of sands with hydrocarbon shows. In view of well-established Kamalapuram Canyon-fill Play in Nagapattinam Sub-basin towards south; the Erumbur Channel sands of Kamalapuram Formation in Ariyalur-Pondicherry Sub-basin can be prospective for Tertiary Exploration in this part of Cauvery Basin.

Introduction

Submarine meandering channel-levee complexes along with features like point bar, crevasse splay, etc. akin to fluvial systems have been observed in many of the global deep sea fans such as Amazon Fan (Pirmez & Imran, 2003), Congo fan (Babonneau et al, 2010), Mississippi Fan (Pickering et al, 1986), Nile Fan (Loncke et al, 2002), etc (Posamentier & Kolla, 2003 for overview). These are significant for oil & gas exploration as they engulf significant volumes of hydrocarbons. For e.g., the Tertiary deepwater channel deposits in Block-17 of Angola Offshore has been estimated with a recoverable reserves of 3-3.5 BBOE with individual well production rates ranges around 4700-14000 BOPD (US EIA report, 2015).

Paleocene Kamalapuram canyon-fill sands are well established prolific hydrocarbon reservoirs in Nagapattinam sub-basin of Cauvery basin, SE India. However, these sands are mostly unexplored in the northern Ariyalur-Pondicherry sub-basin. The present study reveals the presence of two canyons viz., Radhapuram and Erumbur Canyon in this sub-basin at K/T (Cretaceous-Tertiary) boundary from the high resolution 3D seismic data. Further attribute studies were attempted for the detailed analysis of the Kamalapuram channel sediments in Erumbur Canyon, to demonstrate the variations in reservoir facies and the presence/absence of strati-structural entrapment conditions along the channel.

Geological Setting

Cauvery basin is an intracratonic rift basin evolved during Late-Jurassic-Early Cretaceous break-up of Indian plate from East Gondwana and transformed into passive margin during Tertiary. Cauvery Basin contains several NE-SW trending horst-grabens, in which Ariyalur-Pondicherry sub-basin is the northernmost depression (Fig. 1). It is bounded by Basement margin fault on NW and by Kumbakonam-Madanam Ridge on SE. This ridge is transected by a NW-SE cross-trend, which has resulted in a low adjoining the highs (Rangaraju et al., 1993).

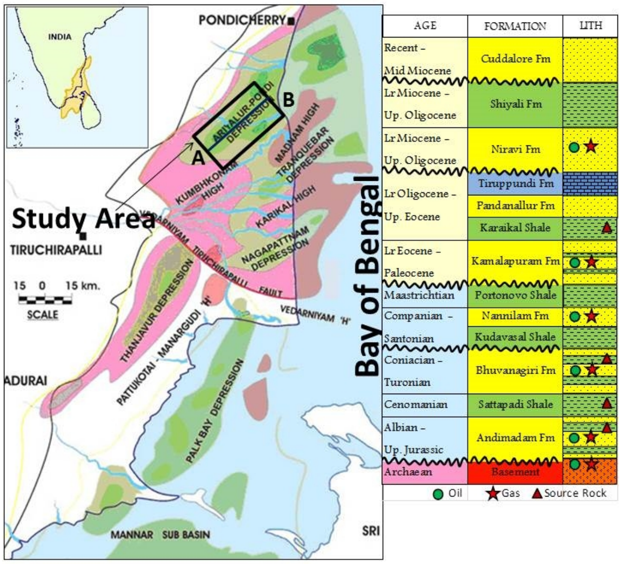

Figure 1: Tectonic map of Cauvery Basin showing study area and generalized stratigraphy of Ariyalur-Pondicherry Sub-basin (Rangaraju et al, 1993). Line AB is the orientation for seismic section in figure 2.

The rifting activity during Late Jurassic-Albian was characterized by deposition of fluvio-shallow marine synrift sediments. It followed by the thermal subsidence, anticlockwise rotation and tilting of Indian plate during the Upper Cretaceous led to the open marine conditions characterized by thick post-rift shales interbedded with mass transport deposits of sands during intervening regressive events. The regressive erosional activity during Santonian and K/T boundary led to the development of canyons associated with channel fill, debris flow and fan deposition of Nannilam and Kamalapuram formations. Passive margin setup was established by Eocene.

Ariyalur-Pondicherry sub-basin contains several oil & gas pools from Up. Cretaceous Bhuvanagi & Nannilam, Synrift Andimadam formations and Fractured Basement from the adjoining Madanam high. Also, in a recent discovery, Lower Eocene sands of Kamalapuram formation are proved be oil & gas producers in Madanam Area. However, the Kamalapuram sands (Paleocene and Lr. Eocene) are unexplored in this sub-basin, except few initial attempts. As Kamalapuram channel sands are oil & gas producers in several fields in the southern Nagapattinam sub-basin; it is worthy to study the Paleocene Kamalapuram sands of study area in detail for its hydrocarbon prospectivity in light of merged high resolution 3D Seismic data.

Methodology

A part of merged 3D seismic data covering an area of 1100 SKM comprising 1200 Inlines & 1150 Traces with 40x20m bin was chosen for seismic interpretation. The two regional markers, i.e., K/T top & Kamlapuram formation close to Paleocene top were mapped after seismic to well tie, which brought out two prominent canyons in this area at K/T level (Fig. 2).

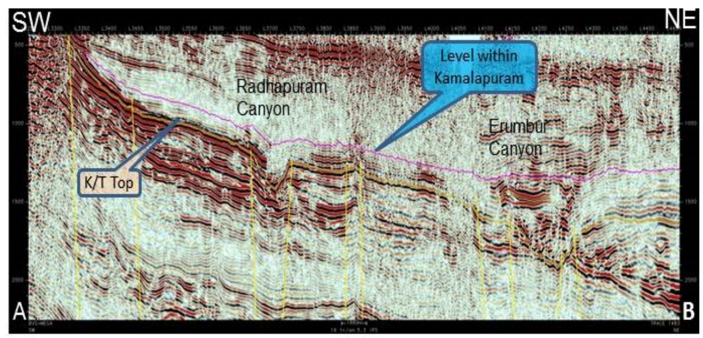

Figure 2: NE-SW seismic section across study area (Line AB in Fig. 1) showing the presence of two canyons at K/T level.

For better understanding of these canyon fill sediments, several attributes were generated such as RMS amplitude, Sweetness, Spectral Decomposition, Amplitude filtering. Nature of channel fill sediments was studied from few drilled wells in the channel to validate the present study.

Results and Discussion

The time structure map at the K/T boundary displays the geometry of both the canyons in the study area (Fig. 3). The Western Radhapuram Canyon trending WNW-ESE and is narrower (1-2.5km of width and 15km of length) with a maximum depth of 1900m (1600ms in time domain). The Eastern Erumbur Canyon is wider (3-4km wide) and longer (18km long before fan out area at south) swerving N-S to NW-SE with maximum depth of 2400m (2000ms). Both canyons are fault bounded. The mapped major deep-seated NE-SW & NW-SE fault systems extend upto Andimadam level.

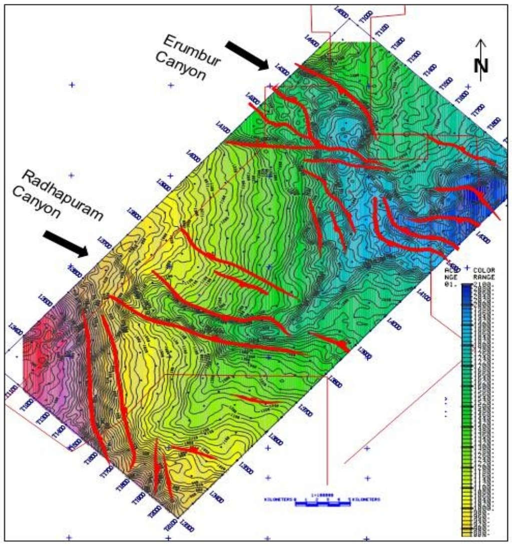

Figure 3: Time structure map on top of K/T in the study area.

RMS amplitude attribute was generated for the window between Paleocene Kamalapuram level and K/T top. It clearly brings out high amplitude anomaly in Erumbur canyon (Fig. 4). A sinusoidal meandering channel feature and a large arcuate body representing a cut-off point bar in the central part of Erumbur canyon was observed, which is also indicating the presence of better reservoir facies. Radhapuram Canyon is devoid of such high amplitude except at the distal/basin floor. A very high amplitude linear feature was observed at the bank, which was found to be a limestone in the well R (Figs. 2 & 9).

The frequency slices from spectral decomposition also confirm the presence of the submarine channel and the cut-off point bar body at the concave side of the channel from 10 to 30Hz, though thery are best tuned at 20Hz (Fig. 5A). The high spectral amplitude was observed at the cut-off point bar and mid channel, which is probably due the presence of hydrocarbon. The high amplitude anomaly within mid-channel is an anticlinal body in the seismic section (Fig. 5C) where as the cut-off point bar shows its typical Swale-ridge structure with sigmoidal reflectors (Fig. 5D) and both are four way strati-structural closures.

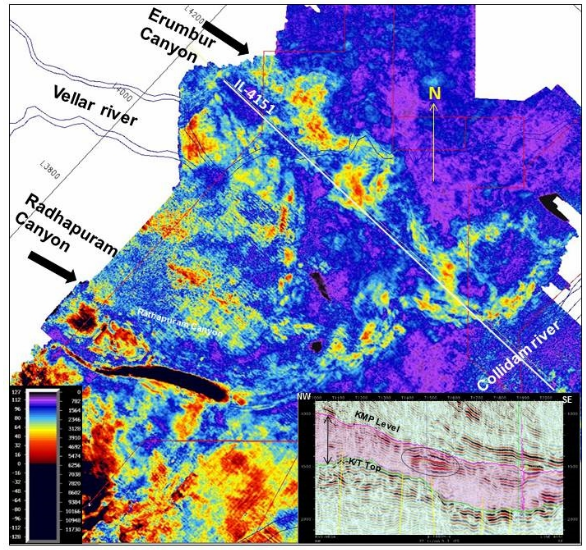

Figure 4: RMS amplitude attribute map for the window between K/T top and Paleocene Kamalapuram level.

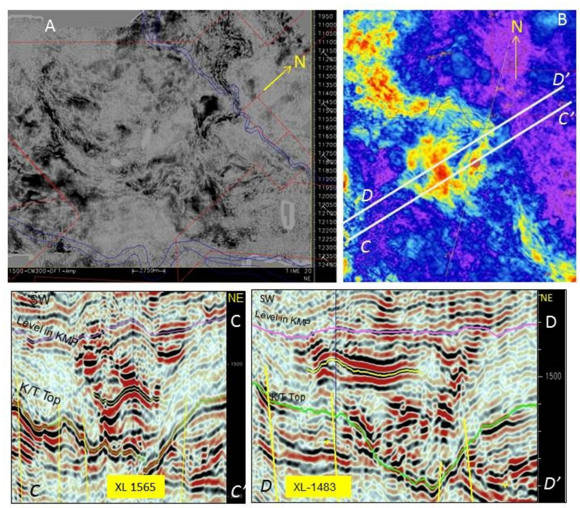

Figure 5: (A) Frequency Slice at 20Hz showing the Erumbur channel and point bar. (B) RMS amplitude index map for the seismic sections that are showing mid-channel anticlinal body (C) and point bar feature towards the left bank (D).

The channel units are alternating high-low amplitude reflectors, where as the levee/banks are transparent section (Fig. 5 C&D).

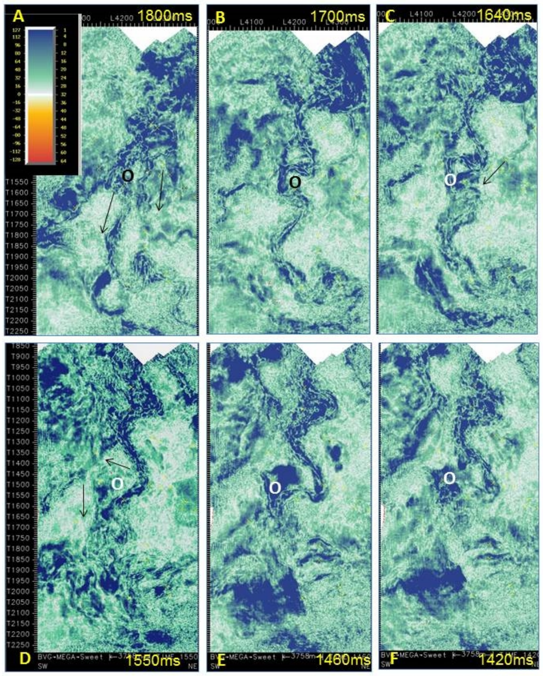

Figure 6: Sweetness time slices from 1800ms to 1420ms showing the changing course of Erumbur meandering channel and the chute cut-off at O. (A) Presence of two linear major channels (arrows). (B) Meandering at O. (C) Beginning of neck joining. (D) Presence of active channel system in both loops leads to continuation of point bar accretion. Additional contribution from an upper tributary is also seen (arrows). (D) Abandoned point bar. (F) Cessation of channel activity.

Sweetness attribute volume was generated and it shows relatively higher sweetness along Erumbur channel & cut-off point bar thereby corroborating the results of RMS amplitude and frequency slices (Fig.6). The sweetness times slices from K/T boundary to Kamalapuram formation (bottom to top) shows the shifting the course of meandering channel complex through time, as the initial meander loop at point O (Fig. 6B) was chute cut-off at a later time by leaving the abandoned point bar (Fig. 6E) at its concave side. The channel activity was ceased after 1420ms.

For further understanding of the spatial geometry and distribution of channel bodies, amplitude extraction filtering and volume rendering has been carried out. Several high amplitude isolated geobodies emerged in Erumbur Channel (Fig. 7), in which the cut-off point bar was the largest isolated body with an area of 10 sq.km.

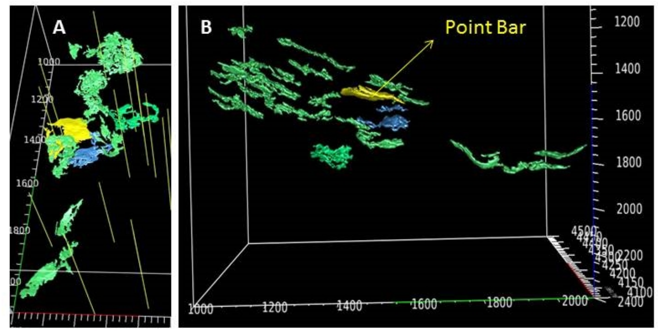

Figure 7: Distribution of high amplitude geobodies along Erumbur Channel. The yellow isolated large body is abandoned point bar and the pink body is the anticlinal body in mid-channel in Fig. 5C.

Reservoir Facies in Erumbur & Radhapuram Canyons

In Erumbur Channel, three wells have been drilled which have confirmed the presence of sandstone in Paleocene channel fill (Fig. 8). It implies that the high amplitude features in channel corresponds to sand bodies. The well E drilled in the proximal part of the channel, shows numerous fining upward sands with thin alterations of calcareous hard streaks and clay beds. The sands are highly calcareous, coarse to medium grained, ill-sorted suggesting the high energy channel environment. The well B drilled in the periphery of channel at central part shows box type to fining upward sequences (in electrologs) of thin sand bodies coupled with hydrocarbon shows during drilling. The sands are fine to medium grained and well sorted and belong to the mid-feeder channel facies.

The well M was drilled in the distal part and shows two different sand bodies separated by thick claystone. The bottom sand is a fining upward sequence, which could be the earlier channel facies. The upper sands are thin and showing serrated to funnel shaped character which is typical of distal fan facies. These sands are very fine to medium grained, well sorted, indicating the low energy environments. These sands also recorded hydrocarbon shows during drilling. Lack of updip entrapment appears to be cause for accumulation of hydrocarbons in these wells (Fig. 8 inset). The well P situated at the levee of channel, which shows total argillaceous section in Paleocene (Fig. 8).

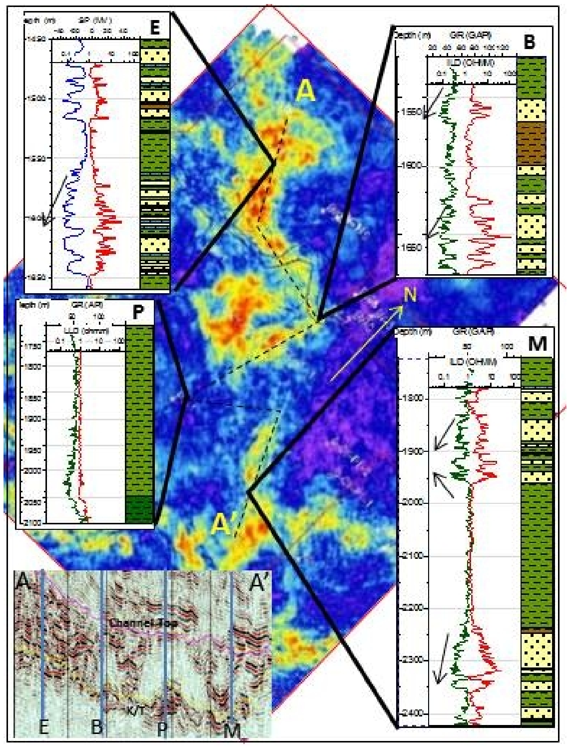

Figure 8: Log motifs of Paleocene channel section in wells E, B, P & M drilled in Erumbur Canyon area showing the presence of sands. The well P is on the outer bank of the channel. The inset seismic section is RC line (AA') along these wells in channel.

In Radhapuram Canyon, The proximal part is devoid of high amplitude (Fig. 9). The well R drilled at the levee of proximal part and it shows a thick claystone with a limestone in Paleocene, corresponding to very high amplitude in RMS amplitude map (Fig. 9B). The wells K1, K3 drilled in the distal/ basin floor, which shows presence of thin fine sands of serrated nature in electrologs, typical of distal fan character.

The study of reservoir facies in both the canyons suggest that Erumbur canyon was experienced active channel activity by receiving coarser clastics throughout Paleocene, while the Erumbur canyon was dormant throughout the period by the deposition of finer clays (proved by transparent section and wells drilled in) except the initial erosional activity dumped the sediments at the distal basin floor area near to well K1 and further.

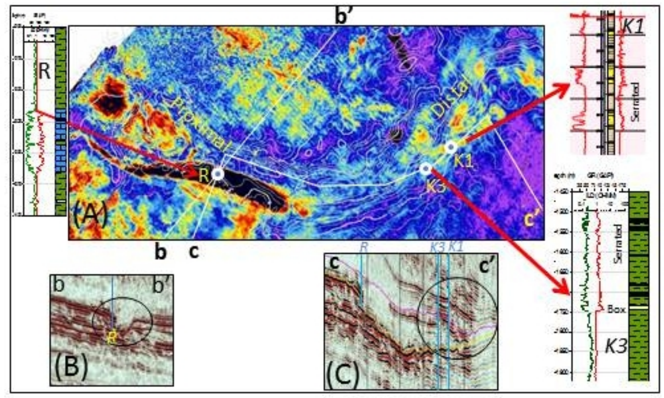

Figure 9: Log motifs of the wells R, K1 & K2 drilled in Radhapuram Canyon showing the lithofacies distribution in Paleocene. Well R at the bank of proximal canyon showing limestone in Paleocene & high amplitude at bank and transparent area in canyon from seismic (B). The wells K3 & K1 drilled in the distal/basin floor shows the presence of thin sands (C).

A study was carried out at top of K/T level to analyze the geometry of both the canyon floors (Fig. 10). The Radhapuram canyon is having a steep gradient, but erosion activity was limited upto depth of 1930m, suggesting it as a dominantly erosional canyon initially, and became dormant at later stage (which is also corroborated by seismics). Whereas the Erumbur canyon cuts into deeper depths (upto 2500m), but is characterized by alternating steep to gentler slope gradients. This explains the meandering loop migration and presence of chute-cut off point bar in Erumbur Canyon. It can be classified as erosional-aggradational canyon.

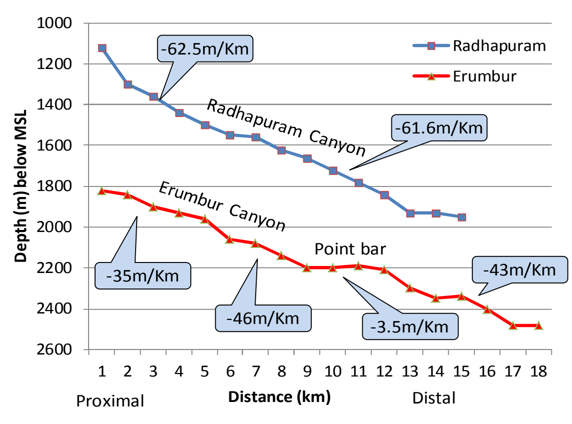

Figure 10: The slope analysis of both the canyons from proximal to distal part. The low gradient area in the middle part of Erumbur canyon is where the cut-off point bar was located.

Hydrocarbon Prospectivity

Synrift Andimadam and Sattapadi Shales are regional source rocks. In addition, Turonian Bhuvanagiri shales are effective source rocks in Ariyalur-Pondicherry Sub-basin (Source Rock Handbook-2013, RGL-Chennai). The canyon activity erodes the entire Nannilam formation, which brings the Paleocene channel fill near to the kitchen (Fig. 2). The presence of deep seated major faults extend from Andimadam formation upto Paleocene, might act as conduits for migration of hydrocarbons. The migration is confirmed by hydrocarbons shows in Paleocene channel sands in the wells drilled in Erumbur channel. High amplitude bodies in Erumbur channel corresponds to reservoir facies as corroborated by the drilled well data. Hydrocarbon accumulation is highly possible provided the existence of strati-structural closure in channel bodies. Two such high amplitude bodies are observed i.e., an abandoned point bar and a mid-channel body having good strati-structural entrapment conditions. The lateral seal is the shales in the bank and top seal is the overlying Up. Eocene Karaikal shale. Several other geobodies in this channel having the similar strati-structural entrapment also requires further study for their potentiality.

Conclusions

The seismic interpretation in the Ariyalur-Pondicherry Sub-basin has brought the geometry of Erumbur and Radhapuram canyons. The former has witnessed active meandering channel system while the latter is a dormant canyon. Erosive and aggradational action was pronounced in Erumbur canyon. The shifting of meanders with time led to the development of an abandoned point bar which is having exploratory interest in view of its high amplitude and strati-structural entrapment conditions. The study also brought out a four-way closure in the mid-channel facies. The wells drilled in the Erumbur channel confirms the presence of reservoir facies in Paleocene channel fill coupled with hydrocarbon shows. The multi-attribute study followed is highly useful in delineating the channel geometry and reservoir distribution. Testing these geobodies of Paleocene Kamalapuram channel sequence may boost the Tertiary exploration in Ariyalur-Pondicherry sub-basin of Cauvery basin.

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