Syn-rift exploration in Cambay Basin with examples from Ahmedabad Sector

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Summary

Cambay Basin, a narrow, elongated and aborted rift basin, is one of the oldest petroliferous basins of India. Post-rift sediments are extensively explored and contribute significantly to hydrocarbon production; however, the syn-rift sediments received only a meagre exploratory efforts because of poor quality of seismic images, greater depth of occurrence, and poor reservoir facies. As a result, only 17% of their hydrocarbon potential is established so far (Gupta U.K. *et al*).

Integrated geological and geophysical study of Ahmedabad Sector of the Basin has brought out two prominent fault systems namely, N-S to NNW-SSE trending listric normal faults and ENE- WSW to E-W trending transfer faults controlled by pre-existing structural grains of the Basement . Rifting along these faults has given rise to a series of asymmetric half-grabens and horsts during Paleocene, which provided accommodation for syn-rift sediments. The early-rift sediments, ie, Olpad Formation, were deposited in a fluvio-lacustrine environment as slide/dump/fan deposits following a transverse and axial drainage system on the slopes of low-relief horsts/grabens and contain reservoir facies amidst finer clastics. These deposits form upward thinning wedges which onlap the rising flanks of the grabens. Five such wedges has been identified in Sanand-Nawagam area in the present study. These syn-extensional wedges could be favorable locales for hydrocarbon accumulation and may be explored expeditiously.

Introduction

Cambay Basin (Figure 1), one of the earliest commercial petroliferous basins of India, is at mature stage of exploration. Almost all the structural highs and stratigraphic prospects of post-rift sediments have already been explored in the Basin and accounts for most of the oil fields discovered. Syn-rift sediments, barring a few localities (eg Nawagam), are barely explored due to poor quality of seismic data (prominent among the reasons being- seismic acquisition parameters were not designed to image syn-rifts as these were not exploration targets then, and, absorption of seismic energy in post-rift coal seams), greater depths and poor quality of reservoir rocks. As a result, only 17% of their hydrocarbon potential is established so far. Acceleration of exploratory efforts for syn-rift sequences cannot be overemphasized in view of ever growing energy hunger of our Nation. This paper relooks into the prospectivity of syn-rift sediments of Ahmedabad sector of Cambay Basin.

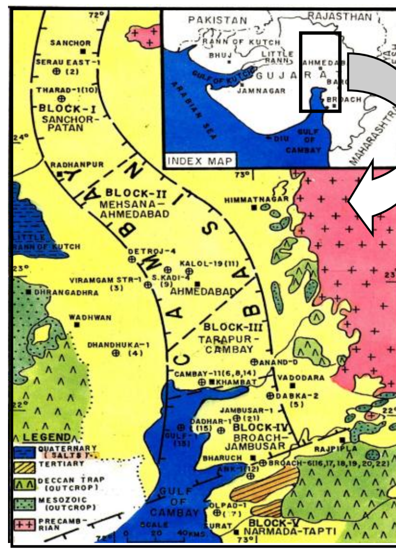

Figure 1: Location Map of Cambay Basin

Tectono-stratigraphy of Cambay Basin

Cambay Basin is an aborted intra-cratonic rift basin in the Western margin of the Indian craton . It is a narrow elongated (NNW-SSE) extensional basin, extending from Luni River in the north to Tapi River in the south. It is about 425 kms in length; however, the width of this Basin progressively increases from 40 kms in the north to over 100 kms towards south. The Basin was formed close to the Cretaceous – Tertiary boundary (KTB) which is marked by Deccan Trap volcanism. The Basin owes its origin to rifting along Precambrian tectonic trends-in other words, pre-existing crustal weak zones- *ie*, Dharwar (NNW-SSE), Aravalli (NE-SW) & Delhi-Satpura trend (E-W to ENE-WSW) which has controlled the tectonic style of the Basin. The Trap volcanism is attributed to the hot spot activity by the Reunion Plume that triggered the separation of Seychelles from India). The Deccan Trap basaltic flows (up to 3km thickness) over the post-Proterozoic granitic / metamorphic basement rocks formed the technical basement over which Cenozoic sediments (7-8km

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thickness) were deposited. The syn-rift extensional regime lead to formation of multiple asymmetric half-grabens with major/active faults (listric in nature) predominantly occurring towards western side (of the half-grabens).

Analogous to many other rift basins, the tectonic and stratigraphic history of Cambay basin is characterized by three phases of evolution i.e. pre-rift (Pre-Cambrian to Cretaceous), syn-rift (Paleocene) and post-rift/rift-fill phases (Eocene to Recent). Each phase involves a separate and distinctive basin geometry, structural style and lithostratigraphic succession. Figure 2 depicts the

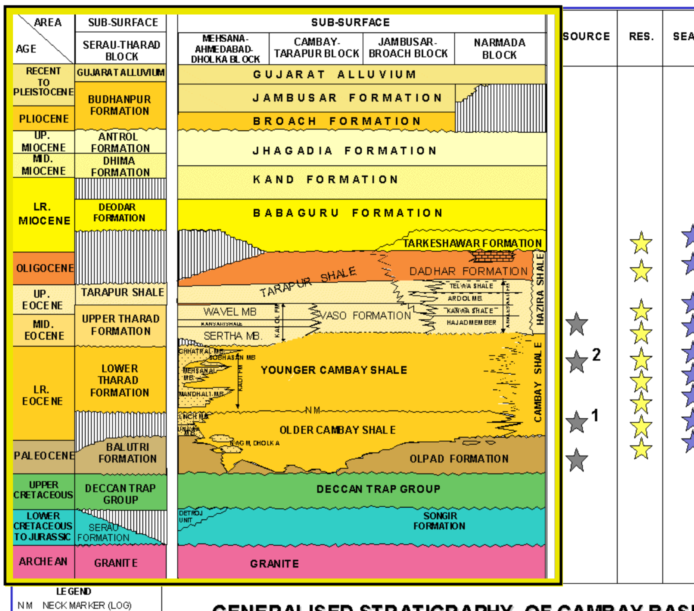

Figure 2: Generalized tecton-stratigraphy of Cambay Basin

Fig.2 GENERALISED STRATIGRAPHY OF CAMBAY BASIN

The syn-rift stage (Paleocene) is characterized by three stages - early rift, rift climax and late rift (Figure 3). Characteristic features of the three stages are:

Early-rift:
Rift initiation; fault block compartmentalization, weak tilting of fault blocks; deposition of immature (coarse, unsorted and angular) sediments, derived mainly from rift shoulders, over grabens in a low-relief topography as slide/slump/alluvial fan deposits, axial drainage in a newly developed fluvial/lacustrine environment *eg* bottom part of Olpad Formation.

Rift-climax:
Rate of basin subsidence exceeds rate of sedimentation, deepening of basin, maximum tilting of fault blocks, development of a series of horst-graben systems, maximum relief of basin floor topography, deposition of finer clastics (which serves as source rock) in deeper part of basin *eg* Cambay Shale.

Late-rift
Rate of subsidence of basin lags behind rate of sedimentation resulting in filling & shallowing of basin, elimination of relief and deposition of coarser clastics (reservoir rock) *eg* Mandhali Formation.

The syn-rift phase is followed by post-rift phase during which the basin witnesses cessation of rifting, uniform subsidence and passive draping of syn-rift sediments by post rift sediments eg Kalol Formation.

During Late Miocene to Early Pliocene time, Cambay Basin witnessed mild inversion activity related to Himalayan Orogeny which resulted in reactivation of earlier faults and inversion structures.

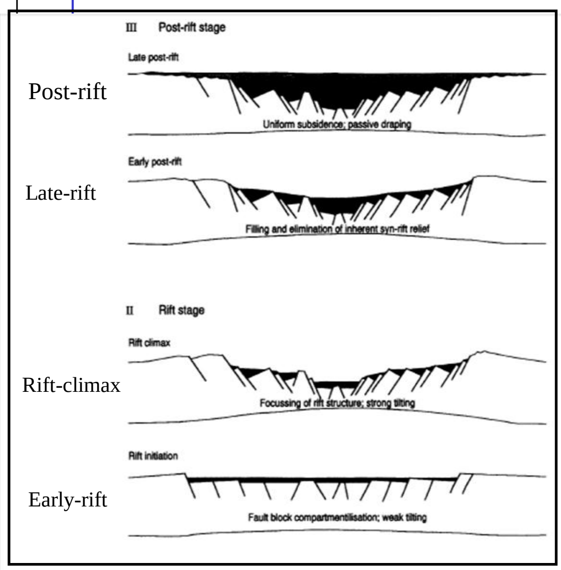

Figure 3: evolution of a rift basin during syn-rift and late-rift phase. (after Nottvedt *et al*, 1995)

Methodology

The present study is based on the interpretation and integration of various data (regional seismic lines, electolog, well completion reports, laboratory studies (sedimentological and biostratigraphic), Figures 4,5,6 and7) and the previously published work on Cambay basin. Time structure map at Trap Top, Rift-climax and Syn-rift Top and isochronopach maps are prepared and integrated (Figure 5, 6) with log data and laboratory data to understand structural framework, thickness variation, sedimentation pattern, facies variation and depositional history of syn-rift sediments. A model for possible hydrocarbon accumulation is attempted.

Tectono-stratigraphic architecture *vis-a-vis* prospectivity

Analysis of isochron maps corresponding to top of Deccan Trap, Rift-climax & Syn-rift top (Figure 4) suggests two sets of fault systems - NS to NNW-SSE-trending normal listric (longitudinal) faults intersected by ENE-WSW-trending transverse faults).

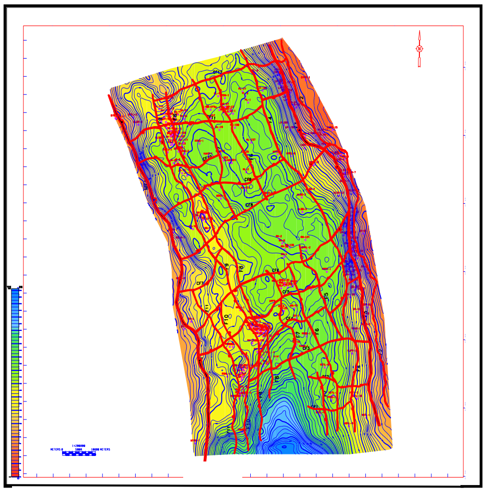

Figure 4: Time structure map of Syn-rift top

Analysis of isochronopach maps (Figure 5) suggests that Wamaj-Jetalpur low was a major depocentre during syn-rift time. Nardipur low, which was a major depocentre during post-rift sedimentation, remained subdued during syn-rift time, suggesting shifting of depocentre.

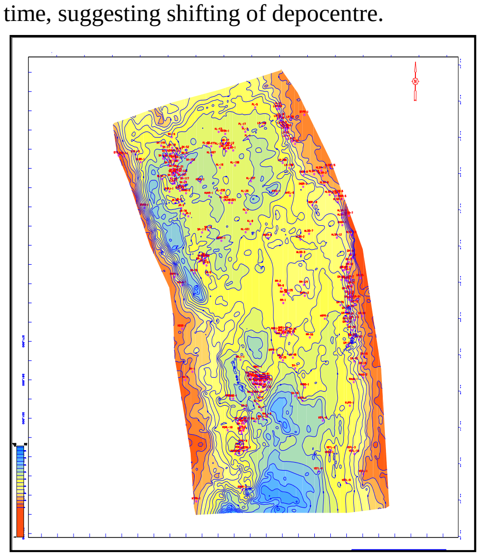

Figure 5: Isochronopach map of early-rift sequence

During early-rift phase, Wamaj- Jetalpur remained a major depocentre in comparison to Tarapur low. However, during late-rift stage, Tarapur low become more pronounced suggesting a shifting of slope during this interphase

Seismic & log interpretation and laboratory studies suggest that during early-rift phase, sediments comprised mainly of conglomerate, fanglomerate & clay facies derived from Deccan Trap exposed on the rift shoulder (Figures 6, 7, 8 and 9). Due to tectonic high rate of subsidence and widening of grabens, more accommodation has been created for deposition of thicker sediments during rift-climax phase. During this phase, intra-grabenal highs got submerged and mostly finer clastics got deposited. During late-rift stage, most of the faults died out and the basin floor became a peneplain over which post-rift sedimentation took place

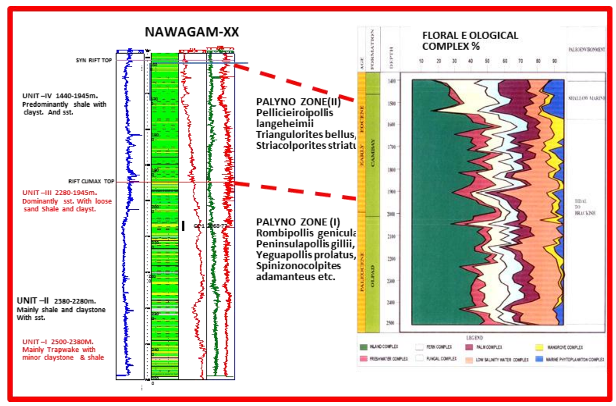

Figure 6: Log motif and floral assemblage of a well in Nawagam field

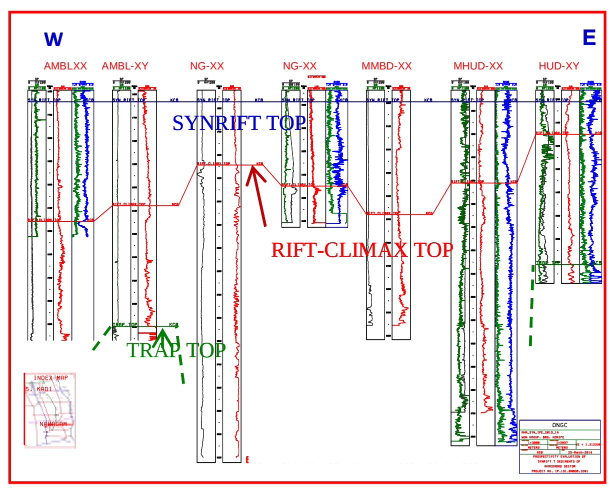

Figure 7: An E-W log correlation profile across Ambliala-Nawagam-Mahuda Structures

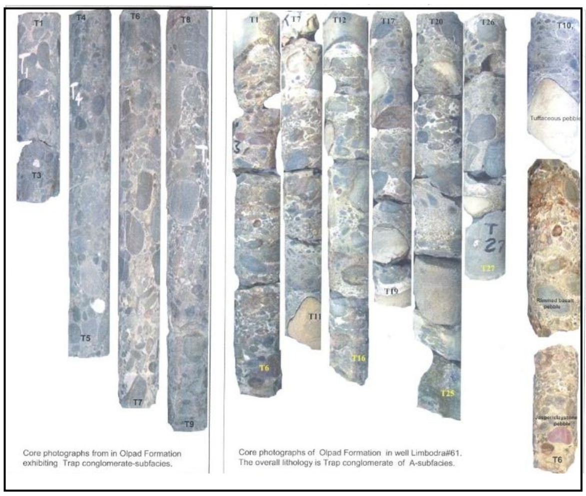

Figure 8: Photograph of cores in two wells of Limbodra showing conglomeratic facies of early-syn-rift sediments

.Transverse as well as axial drainage pattern is envisaged during early-rift period. Newly developed fluvial systems

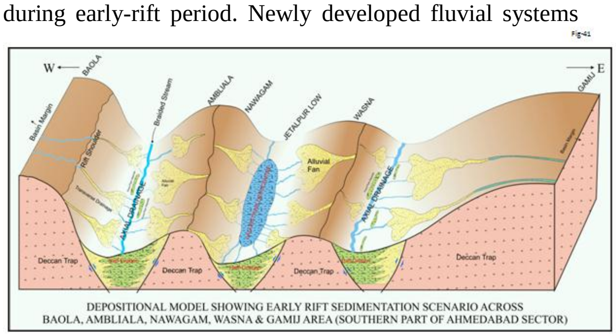

Figure 9: Fan model with transverse and axial drainage for early-rift sediments

descending down the footwall and hangingwall slopes of half-grabens/horsts (transverse drainage) deposited E-W-oriented alluvial fans and formed N-S axial drainage on the graben floor with lacustrine environment along paleo-lows. (Figure 9). This type of structural style and sedimentation pattern facilitated deposition of wedge-shaped reservoir facies that thin upward forming (subtle) stratigraphic traps. (Figure 10). Because of limited seismic resolution and sparse well data, the architecture, thickness, and distribution of these early syn-rift reservoirs are often difficult to predict and need a model-based exploration strategy.

The rift-climax sediments (Older Cambay Shale) were deposited as transgressive / pro-deltaic shale, with occasional high energy sediments at shallower parts of the Basin. It is established as a play at few localities, *eg* South Kadi field. Effort is required to established similar pays at other parts of the Basin.

The prospectivity of late-rift sediments (Mandhali) is established in the northern-most part of the Basin, leaving behind a vast area for exploratory inputs.

In addition to wedge-out prospects, other entrapment models envisaged for syn-rift plays are- fault closures along rising flanks of half-grabens, synchronous sands on structural highs and fanglomerate deposits adjacent to highs (often with a seismic expression of high amplitude events)

The shale sequence within Olpad and Cambay Shale Formations are established as source rock for syn-rift and post-rift reservoirs. Longitudinal/transverse normal faults provide conduits for migration into syn-rift sediments

In the present study, five syn-rift wedges have been identified & seismically mapped in the area around Sanand high and Miroli-Nawagam high.. In the example presented here (Figures 11a and 11b), the wedge rises towards east from a central low and tapers towards east too from a centrally thick part, thus creating stratigraphic entrapment

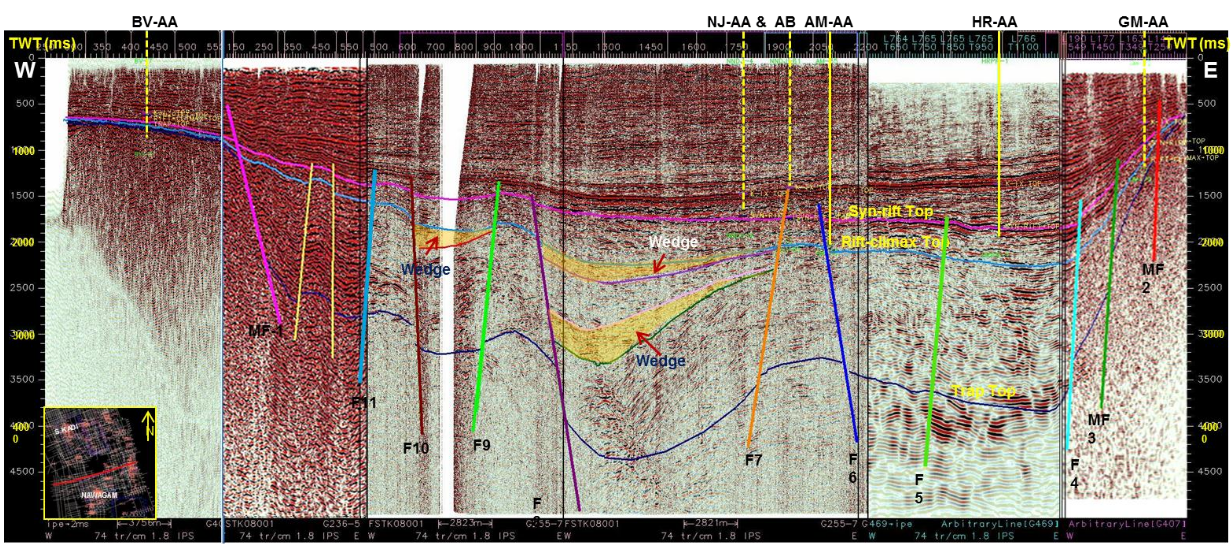

Figure 10: E-W regional siesmic line passing through Nandej, Hirapur & Gamij area.showing clastic wedges.

condition. These wedges could be locales for hydrocarbon accumulation. Similar wedges, which are more likely to occur in many places of the basin, may be explored expeditiously.

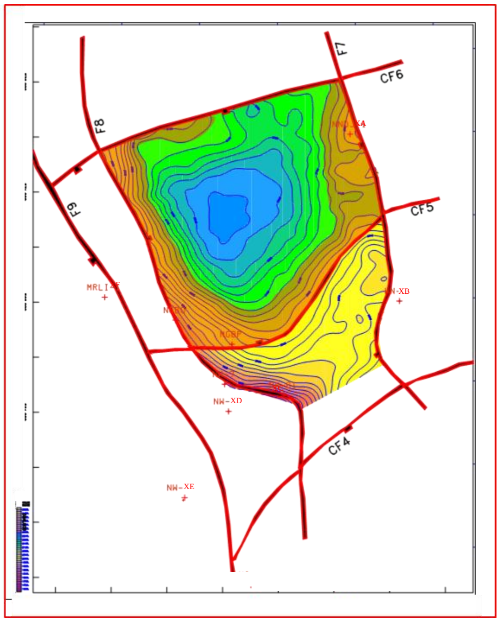

Figure 11a: Time structure map at the top of a clastic wedge in Nawagam field

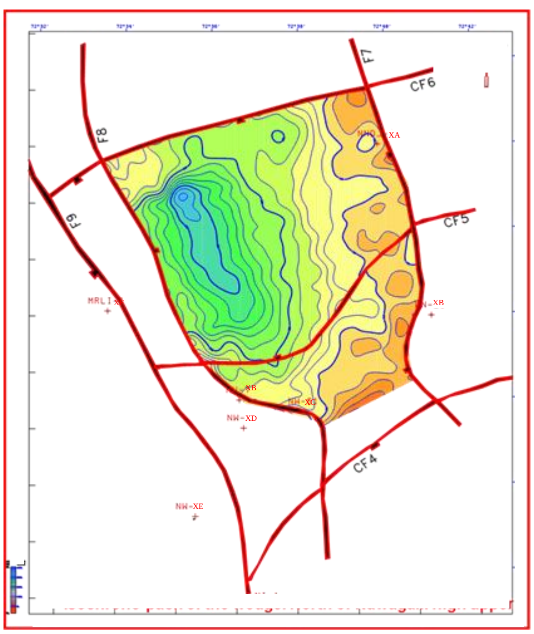

Figure 11b: Isochronopach map of the clastic wedge presented in Figure 11a

Conclusion

In a mature basin like Cambay Basin, lookout should be for new pays, if any, to give a fillip to the (dwindling) production, even if the uncertainty is higher. The post-rift sediments are extensively explored and form the dominant producers in the Basin. The syn-rift sediments, to the contrary, got scant attention; as a result only 17% of their hydrocarbon potential is established so far. The study has brought out two sets of faults namely, N-S to NNW-SSE trending normal faults and ENE- WSW to E-W trending transfer faults controlled by pre-existing structural grains of the Basement. Rifting along these trends has given rise to a series of fault-bound asymmetric half-grabens during the Paleocene time, which provided accommodation for syn-rift sediments. The early-rift sediments were deposited in a fluvio-lacustrine environment as slide/dump/fan deposits by a transverse-and-axial drainage system developed on the slopes/floors of low-relief horsts/ grabens and contain reservoir facies amidst finer clastics. The reservoir facies, manifest as upward thinning wedges of high amplitude events, onlap the rising flanks of the graben slopes. The wedges provide stratigraphic/ strati-structural entrapment for hydrocarbons that could be migrating into the reservoir from Olpad/Cambay Shale source rock. Five such wedges has been identified and mapped in Sanand-Nawagam area. Similar wedges, which can be expected to have been formed in the basinal set-up, may be explored expeditiously.

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