



Sediment Architecture of Half Graben Play and Its Hydrocarbon Implication in and around Jetalpur Low, North Cambay Basin, India.

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Summary

Tertiary On land Cambay Rift Basin has been formed as an integral part of Western Margin Rift Basins System of India. Early sixties oil strike near Gulf of Cambay had brought it in the oil map of India. Hitherto exploration and exploitation history of five decades had established it as a classic Petroleum Province with all ingredients of hydrocarbon habitat mainly for multiple Eocene clastic reservoirs. Although majority of world known hydrocarbon accumulation is in Synrift setting, meager conversion (<1%) of presumed oil expulsion capacity could be achieved for synrift play in Cambay Basin leaving a huge scope of untapped Yet to Find (YTF) oil (>99%) potential. The major portion of synrift oil (>50%) occurrence is from intra basinal Nawagam High, located at the western rising flank of Jetalpur Low, a principle kitchen of North Cambay Basin.

The Paleocene syn rift sequence of Cambay Basin has been divided into two sub sequences viz. Danian Climax Stage (Olpad Formation, Lower Paleocene), unconformably overlain by Thanetian Late Stage (Older Cambay Shale ie OCS Formation, Upper Paleocene). Structural framework of the study area has brought out two prominent intra basinal highs, on each rising flank of Jetalpur low. N-S to NNW-SSE trending, basement-controlled fault systems have given rise to asymmetrical fault-bound half-graben during the Paleocene synrift deposition and concomitant accommodation. Stratigraphic entrapment for faulted rising flanks of Jetalpur Low and stratigraphic accumulation within low are prospective locales for quest of YTF hydrocarbon. Reverse modeling from log to core from drilled well data of Nawagam, has resembled that reservoir facies within Olpad sequence has been resulted both during fan progradation (i.e. coarsening up) and fan back stepping (i.e. fining up) in shallower Olpad sequence. The envisaged Olpad depositional model has brought out geological concept based synrift prospect along the dissected eastern steeper limb of Nawagam and western gentler limb of Nandej high in both the rising flank of Jetalpur low as well as within low. A breakthrough can lead to opening up of a new avenue for YTF oil in half graben play of Cambay Basin for Olpad-Olpad petroleum system (OOPS).

Keywords: Danian, Thanetian, Synrift, Half Graben, Back Stepping and Progradation

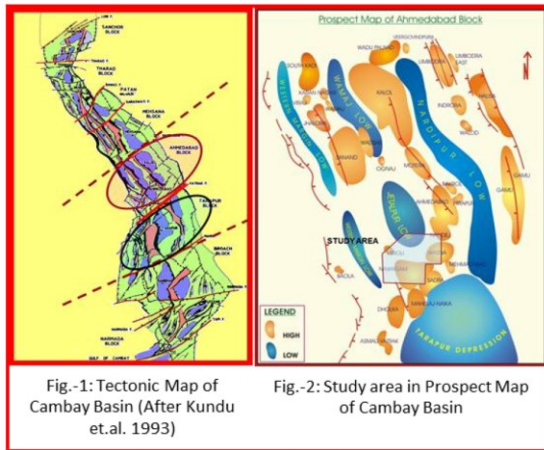
Introduction

The Cambay Basin is an intra cratonic NNW-SSE trending, sigmoidal aborted rift in the west margin rift basin system of India (Kundu et al 1993) (**Fig-1**). Evolution of the Cambay Rift Basin could be divided into pre-rift, syn-rift and post-rift stages. The Cenozoic rift basin was formed as a result of continental rifting (separation of Madagascar and Seychelles Basin from Indian Plate) along western margin of India close to Late Cretaceous-Tertiary boundary triggered by Deccan Volcanism. But synrift sequence had culminated during Danian Rift Climax (Olpad) represented by epiclastics alluvial fan complex and silici clastic lacustrine facies.

Synrift Late Stage Thanetian (OCS) sequence was deposited as transgressive / pro deltaic shale.

The study area covers Nawagam-Wasna-Nandej field and the adjoining area surrounding Jetalpur Low and Miroli High (**Fig-2**). The rift fill deltaic sediments holds majority of discovered oil fields of Early to Middle Eocene age (**Fig-2**). The trap geometries are often related to N-S to NNW-SSE trending, basement-controlled fault systems leading to asymmetric half-graben depocentre. Stratigraphic and stratigraphic entrapment have been envisaged for Paleocene fault controlled syn rift fill systems along rising flanks of principal kitchen and within kitchen respectively as prospective locales for quest of YTF hydrocarbon. This paper dealt with a new insight into

hitherto unexplored OOPS of Cambay Basin in synrift half graben setting based on geological model and mapped seismic geo bodies.



Background

While working on “Quantitative Genetic Modeling of Cambay Basin”, it had been suggested by Ray et.al. (2001) that generation and expulsion potential of Olpad Formation were 29BT (O+ OEG) and 1.4BT 0.48% respectively. The author also opined that expelled hydrocarbon probably had little scope to migrate across the overlying OCS and might have been accumulated within reservoir facies of Olpad/OCS itself envisaging existence of Olpad-Olpad PS (OOPS). Initial five decades exploratory efforts could fetch only 57.34MMt in place oil from Olpad Formation in Cambay Basin. Thus, resource to discovered hydrocarbon conversion (0.041%) from Olpad Formation has suggested that huge quantity of YTF oil potential still exists for conversion to tangible gain, which acts as the bedrock of present work. The majority of this converted reserve base (>50%) had contributed from Nawagam Field itself, rest from Eastern and Western Basin Margin Fields. But this Olpad oil in Nawagam Field is encountered only in the top part of formation i.e. within 100 to 150m. Furthermore, worldwide oil occurrence history in synrift half graben tectonic setting, has prompted a deliberate search for untapped OOPS.

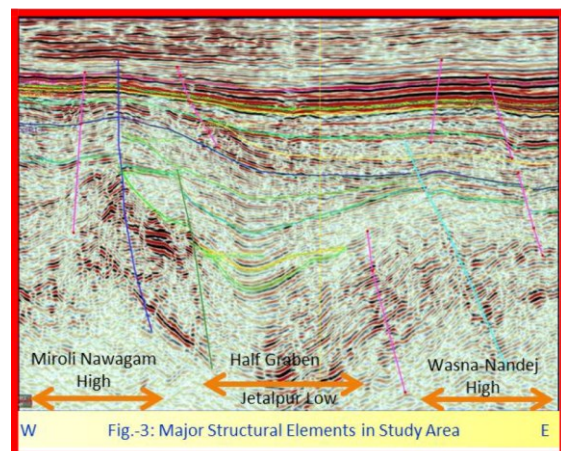
Present Exploration Scenario

Although, initial success for synrift hydrocarbon within Upper part of Olpad Formation could be traced way back in early sixties itself in the Nawagam cross trend, past five decades exploration history in Cambay Basin was focused

mainly on structural traps of four-way dip or fault closures and stratigraphic/stratigraphic traps in rift fill sediments. Sporadic discoveries of Olpad oil from EBM during early eighties and Khamboi area in WBM during late nineties had been reported, but restricted in upper part only. In the study area, altogether around 140 wells atop Nawagam-Wasna ridge have been drilled mainly for top part of Danian Climax Stage of synrift sediments. Excepting Well#G and #H in Wasna Field, Well#A to #F in Nawagam Field and Well#I in Miroli Area, all the wells were terminated within upper part (200m) from Olpad top. Thus, the Cambay Basin is in incipient stage of exploration for half graben synrift play.

Tectono Stratigraphy

Structural architecture of the study area has brought out two prominent intra basinal highs: N to NNW–S to SSE trending Miroli–Nawagam and N to NNE-S to SSW trending Nandej– Wasna high (Fig-3). Both the highs merged to EW trending Nawagam-Wasna Ridge that practically differentiates northern Jetalpur Low from southern Tarapur Depression: two principle kitchens of North Cambay Basin (Fig-3b). Towards north beyond Miroli area, the high amplitude has further reduced and flattened. The area has undergone polyphase tectonic disturbance and imprint of tectonic inversion has been manifested. Time mapping at Danian (Olpad) and Thanetian (OCS) Sequence top and fault correlation have brought out structural architecture of the study area as asymmetric faulted half graben. Towards eastern rising flank of Jetalpur Low, domino fault has been observed with seismic roll over against an east dipping fault both in Olpad and OCS level (Fig-3). Paleo tectonic analysis (Fig.-4) along the seismic inline X,



cross line Y and NE-SW trending RC Lines have depicted basin floor morphology and subsequent synrift accommodation. A conspicuous shift of paleo depositional

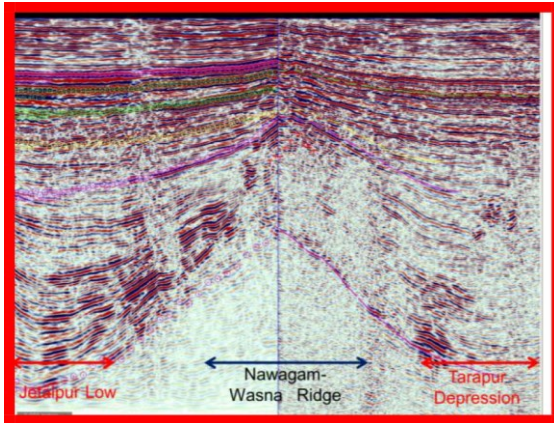
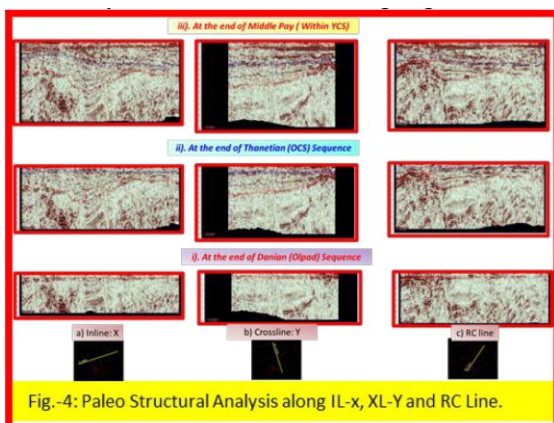


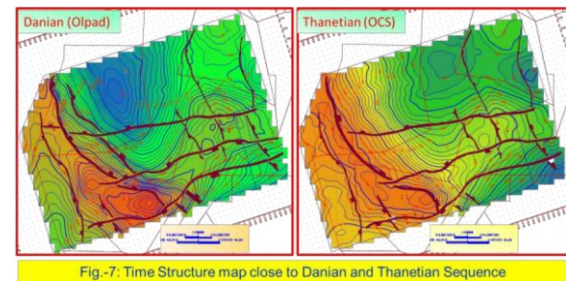
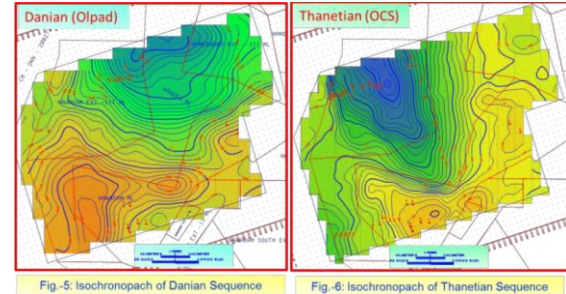
Fig - 3b: Structural disposition of Nawagam-Wasna Ridge.

low from W to E has been observed from Olpad to Shallower Level, corroborating observation of isochronach maps also. Time thickness of Olpad sequence (Fig.-5) has indicated high axis passing west of Nawagam structure and the entire Nawagam-Wasna area was depositional low during Olpad deposition with depo centre in the northern part of Jetalpur low. Isochronach of OCS sequence (Fig.-6) indicates that the area experienced structural reversal and Nandej-Wasna became structural high during OCS deposition. Minimum OCS thickness is observed in Eastern rising flank of Jetalpur while deepest part being North of Nawagam structure. The structural style shows NNW to SSE trending longitudinal fault system associated with synthetic faulting.



The eastern limb of Nawagam has further been dissected into three structural segments by longitudinal and synthetic

faulting (Fig.-7). E-W trending transfer/cross faults have subdivided these longitudinal segments into different rotating fault blocks offsetting longitudinal faults.



The fault controlled negative areas were seats for successive deposition of thick pile of epiclastic alluvial fan sediments derived from Trap escarpments followed by marine (? Pro deltaic) shale punctuated with occasional high energy (sand/silt) pulse. Concomitant subsidence along half graben marginal growth fault with dumping load has resulted in creating new accommodation and subsequent reduction of intra basinal irregularities.

Depositional Model and Sediment Architecture

Worldwide prolific existence of half graben petroleum province is in incipient stage in Indian Basin Scenario. Thus, a conceptualize Geological Model of half graben (Fig.-8) tectonic setting has been prepared for synrift sedimentation. The model envisaged both transverse (EW) and axial (NS) drainage pattern to decipher the probable locale for reservoir development. The transverse drainage pattern from steeper foot wall derived alluvial fans of Nawagam flank and gentler hanging wall dip slope alluvial fans of Nandej/Wasna flank has resulted in deposition of reservoir facies within Olpad. The steep footwall slope is blanketed by coarse debris but the dip slope fans dominate the half graben fill (Miall, 1996). Depositional environment of the synrift sediments were all directly affected by episodic movement on half graben bounding

normal fault. Topography and uplift/subsidence pattern created by Extensional Faulting directly influenced nearly every aspects of synrift sedimentation e.g. thickness, texture, sediment transport direction, litho facies etc. The envisaged trunk channel remained consistently confined towards the axial part of Jetalpur low, flowing both from north and south towards paleo lows (Lacustrine Fill). This low fill sediments of lacustrine facies in the reducing condition has been envisaged to act as a possible source in the model.

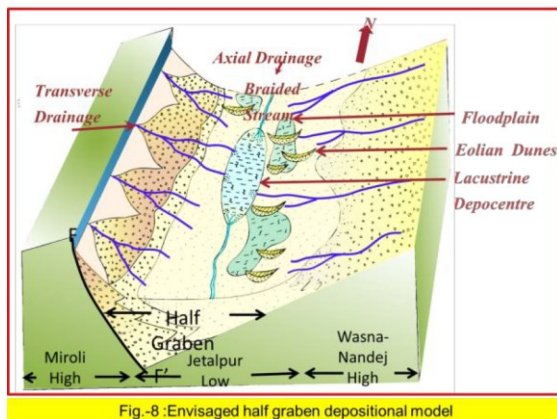


Fig.-8: Envisaged half graben depositional model

Olpad synrift sequence is characterized by admixture of highly heterogeneous lithology comprising of epiclastics representing alluvial fan complex and different clay facies of lacustrine origin. Half grabens setting have accumulated epiclastic conglomerate, lithic sandstone/siltstones and wide spectrum of clay stone ranging from trap wash to highly oxidized haematitic reddish brown clay stones to thinly laminated sideritic organic rich chert (verve deposit, typical of lacustrine facies) to variegated clay stone. These overlies unconformably to chemically weathered and highly altered Deccan Basalt. The sequence comprising of very fine volcani clastic (epiclastics) siltstones, clay stones/shales deposited during synrift phase of basin evolution have represented distal fan to lacustrine conditions, while coarser epiclastics for proximal and mid fan complexes. Quality Olpad reservoir unit is mainly represented by mid fan epiclastic sandstone /siltstone. The sediment influx consisted of detritus from Deccan Trap escarpments. Rapid erosion accompanied by rapid infilling by coarse detritus has occurred concomitant to fault bound subsidence creating accommodation.

OCS consists of lenticular/discrete silts/very fine sandstone partings within gross marine/pro deltaic shale. This lenticular encased high energy sand/silt pulses within

gross shale/clay stone is envisaged as „proper“ progradational/fore stepping) delta in a transgressive setting (back stepping beaches) (Catuneanu, 2006). Three geo bodies have been identified in Olpad based on geological model to divulge OOPS. One geobody in OCS (Fig.-: 9 and 10) has been identified for exploration inputs for synrift half graben play.

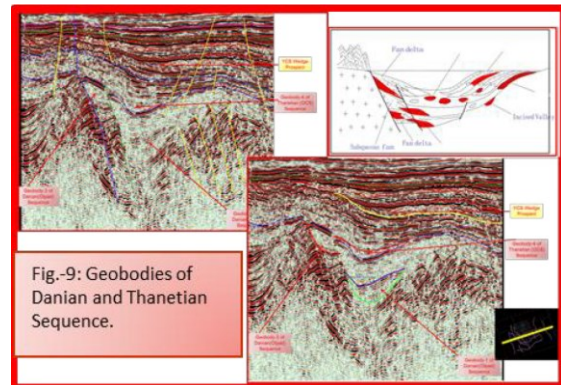


Fig.-9: Geobodies of Danian and Thanetian Sequence.

Olpad accommodation pattern indicates both large scale coarsening upward (Fig.-11) owing to continuous faulting and fan progradation and fining upward sequence due to short faulting phase followed by retreat of scarp front and lowering of relief in the source area or lateral shifting or abandonment of fan (Gerhard 2000). Individual fan lobe progradation has also been observed by small scale coarsening upward cycle pattern in the drilled wells of Nawagam Field. Reverse modeling of core to log data has envisaged both back stepping and pro grading fan complex as possible reservoir locale (Fig.-12).

Synrift Play Concept

Based on the paleo tectonic analysis and sediment filled architecture of synrift sequence concomitant to positive

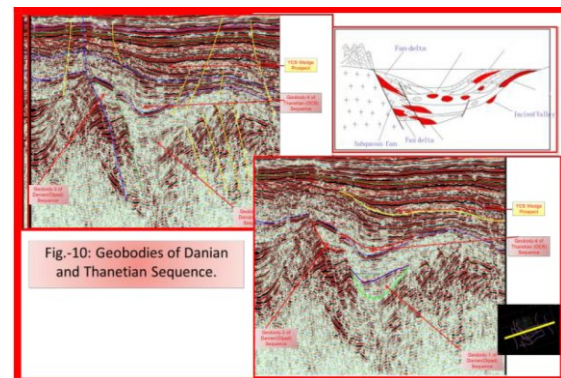


Fig.-10: Geobodies of Danian and Thanetian Sequence.

accommodation and the exploratory leads established so far from drilled wells in the Basin, following play types have envisaged for Synrift Play:

A) Within Tectonic Low :

- Half Graben Fault Closure model for both the rising flanks of Jetalpur low for probing Olpad-Olpad PS.
- Wedge out/ Pinch out Prospect against paleo highs.
- Vertically Drained High Impedance PS.

B) Within Tectonic High/F flank:

- Synchronous sands on structural highs
- Fanglomerate deposits adjacent to highs

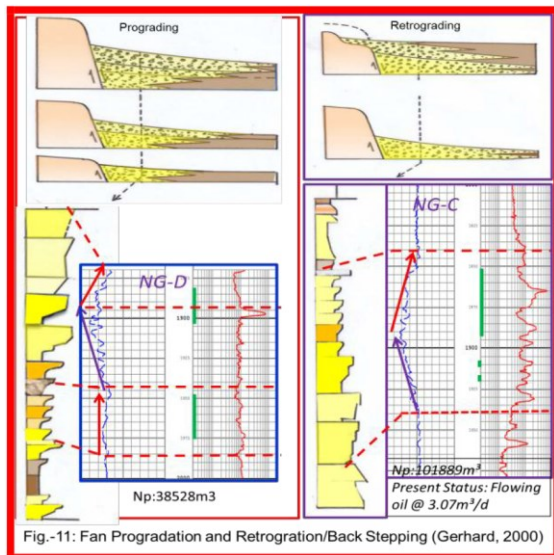


Fig.-11: Fan Progradation and Retrogradation/Back Stepping (Gerhard, 2000)

C) Irrespective of Structural Component:

- Encapsulated sand/silt partings/body within OCS
- Coarser Clastics inputs along Transfer Zone.

Olpad accumulation within the study area is mainly strati-structural located around palaeo/basement highs and rising flanks of adjacent lows with good reservoir facies development. Hydrocarbon distribution pattern within OCS is found to be stratigraphic with reservoir facies development.

Conclusion

A deliberate attempt has been made to probe the existence of OOPS in Cambay Basin with huge envisaged YTF hydrocarbon potential. Tectonic slopes are produced by

combination of footwall uplift and hanging wall subsidence by half graben bounding fault.

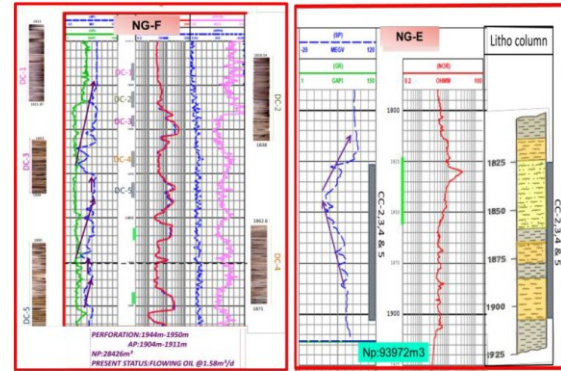


Fig.-12: Reservoir Facies from Core and Log Data in Both Fan Progradation and Retrogradation Well NG-E and F

The steep footwall slope is blanketed by coarse debris. Half graben setting in the deeper part of Olpad sediments have been targeted taking analogy from existing worldwide entrapment model. Lacustrine facies of Olpad has been considered for source rock. Reverse modeling of core to well log have suggested reservoir facies development in both fan progradation and back stepping as observed from drilled wells of Nawagam in the shallower part of Olpad Formation. Fault bound fanglomerate deposits against episodic movement of half graben bounding fault is also identified as possible prospect. The electro log calibration with SWC and conventional core data has brought out higher Rt values for coarser clastics reservoir facies. Both high amplitude and low amplitude seismic facies for the deeper event has been found. Domino fault prospect towards gentler rising flank along with roll over feature against east dipping fault has been identified for exploratory inputs. Altogether, four prospects have been identified. Drilling of these, if found wet, may lead to paradigm shift in hitherto exploration history of Cambay Basin to half graben YTF oil.

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