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Depositional processes and sequence stratigraphic framework of Eocene clastic sequences based on T/R sequence model In the North Cambay Basin

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Summary

Well data, electrologs, litho-biosratigraphy and seismic stratigraphy provide an integrated sequence stratigraphic framework to assess reservoir, seal and source for hydrocarbon exploration. High frequency Transgressive/Regressive (T/R) sequence stratigraphic framework for Eocene depositional sequences has been established in the present work for predictable assessment of petroleum play in the North Cambay Basin. The Cenozoic sedimentary fill in Cambay Basin is represented by two 1st order depositional sequences. The first, 1st order Paleocene rift sequence relates to Seychelles fragmentation. The second, 1st order passive margin sequence from Early Eocene to Recent comprises of several 2nd order sequences. In the Early and Middle-Late Eocene 2nd order passive margin depositional sequences, ten T-R sequences have been identified. Seismic data were calibrated with the well data to understand the structural disposition and depositional set up of the sequences. This study has facilitated inferring of genetic configuration and facies distribution within each T/R sequence. Calibration of paleogeographic set up of each T/R cycle with reservoir facies distribution has helped to evolve depositional model.

Introduction

Publication of AAPG Memoir 26 (Payton, 1977) and Society of Economic Paleontologists and Mineralogists (SEPM) Special Publication 42 (1988) were milestone in the evolution of modern concepts of sequence stratigraphy and brought its widespread applicability into limelight. Sequence stratigraphy is the third major revolution in sedimentary geology after flow regime concept in late 1950s and plate tectonics and geodynamic concepts in 1960s (Miall, 1995). It has developed into the fundamental approach for understanding and predicting the distribution of sedimentary facies and stratigraphic analysis. Using this approach, the stratal stacking patterns are analysed within a temporal framework. These stacking patterns evolve in response to the interplay of accommodation available for sediments to fill sedimentation and reflect combinations of depositional trends that include progradation, retrogradation, aggradation and downcutting.

Cambay Basin is a narrow, NNW-SSE trending extensional rift basin located on western margin of the Indian Precambrian shield. The basin, around 425 km long, extends from Luni River in the north to Tapti River in the south and is intracratonic aborted rift evolved consequent to separation of Greater India from Seychelles at the end of Cretaceous. The basin is superimposed on the Middle Proterozoic Aravalli Craton (Naqvi and Rojers, 1987), bordered by Saurashtra Arch in the west and Aravalli-Delhi fold belt (NE-SW) in the east. The lithostratigraphic framework of Cambay Basin was worked out by Pandey et al. (1993) and has been followed in the present study to firm up the sequence stratigraphic framework of Eocene sequences of North Cambay Basin. In the study area (Fig. 1), which extends from South Patan in the North to Chaklasi-Vaso in the south in Mehsana and Ahmedabad blocks of North Cambay Basin, the Paleocne-Eocene epochs are represented by Olpad, Cambay Shale, Kadi, Kalol and Tarapur shale formations.

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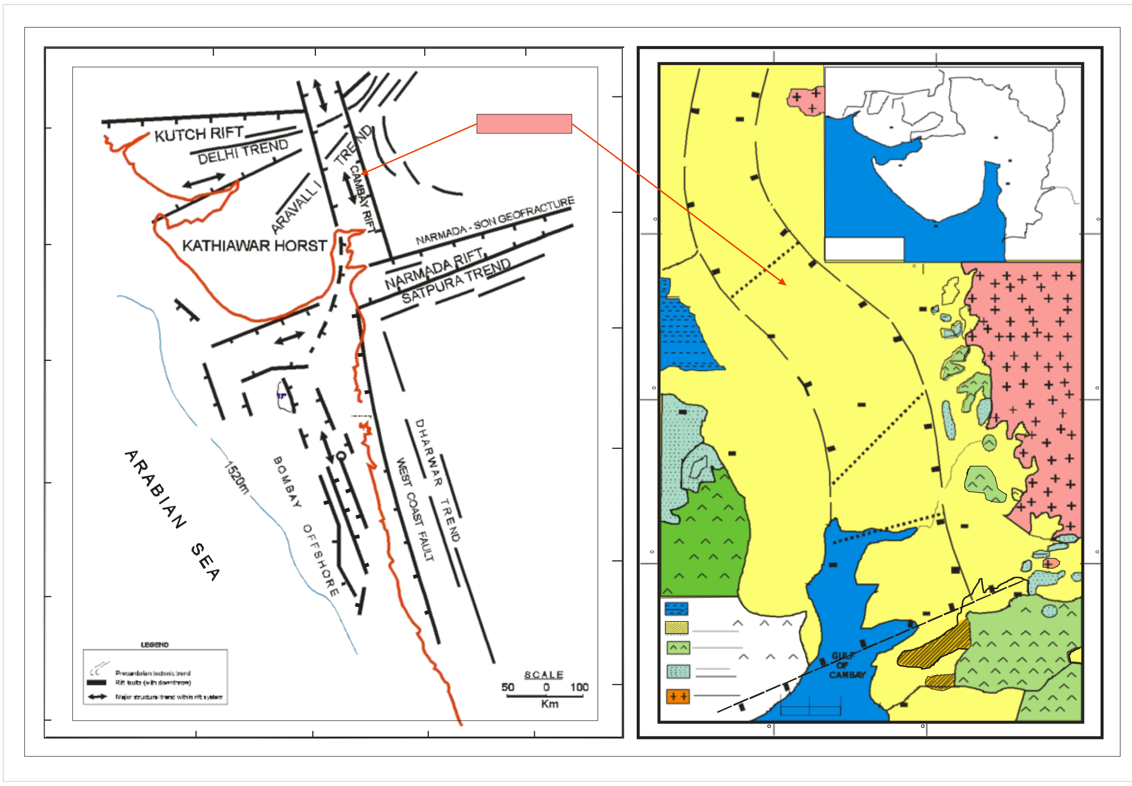

Fig. 1: Tectonic map of Cambay Basin showing study area (Biswas, 1982)

In the present work well data including biostratigraphic studies, electrolgs, core data have been integrated and validated with the seismic data. Accordingly, 2nd order passive margin Early Eocene and Middle-Late Eocene sequences have been correlated with the objective of identifying and mapping high frequency Transgressive /Regressive sequence stratigraphic surfaces, and correlating them along electrolog profiles to facilitate identification of reservoir facies and their distribution.

Sub- surface mapping of the seismic data was carried out to generate the time structure maps at the top of Paleocene, Early Eocene and Middle-Late Eocene sequences. Fault mapping carried out throughout the study area in detail to understand the fault pattern, tectonic framework and possible entrapment structures. Sub-surface relief is also mapped for Top of Trap, Paleocene, Early Eocene and Eocene top surfaces primarily to facilitate the generation of Isochronopach maps of different T/R sequences.

Sequence Stratigraphy: Overview

Sequence Stratigraphy is the analysis of genetically related depositional units, within a chronostratigraphic framework wherein the succession of rocks is cyclic, bounded by unconformities and their correlative conformities. Tectonics, eustasy and climate interact to control accommodation and sediment supply. Marine flooding surfaces and maximum flooding surfaces along with their correlative surfaces or non-depositional surfaces are the main thrust areas for sequence stratigraphic studies.

The term 'sequence' was first introduced by Sloss et al. (1949) for relatively conformable succession of genetically related strata bounded at its top and base by unconformities and their correlative conformities. Subsequently 'sequence' (of Sloss) was formalized by the European "International Stratigraphic Guide" in 1994.

In the beginning after publication of AAPG Memoir 26 and SEPM Special Publication. 42 'depositional sequence' was the main unit of sequence stratigraphic model (bounded by subaerial unconformities on the basin margin and their correlative conformities towards the basinal side) and divided into LST, TST and HST based on shoreline shift pattern i.e. regression to transgression or transgression to regression. 'Genetic stratigraphic sequence', also known as regressive-transgressive (R-T) sequence, term was used by Galloway (1989) for sequence model and opined that maximum flooding surfaces, instead of subaerial unconformities, be used as sequence boundaries. Embry and Johannessen (1992) proposed third type of stratigraphic unit i.e. transgressive-regressive (T-R) sequence, corresponding to a full cycle of transgressive and regressive shoreline shifts. In the present work T/R sequence model of Embry and Johannessen (1992) has been followed (Fig. 2).

Events \ Sequence model	Depositional Sequence II	Depositional Sequence III	Depositional Sequence IV	Genetic Sequence	T-R Sequence
	HST	early HST	HST	HST	RST
end of transgression					
	TST	TST	TST	TST	TST
end of regression					
	late LST (wedge)	LST	LST	late LST (wedge)	RST
end of base level fall					
	early LST (fan)	late HST (fan)	FSST	early LST (fan)	
onset of base level fall					
	HST	early HST (wedge)	HST	HST	

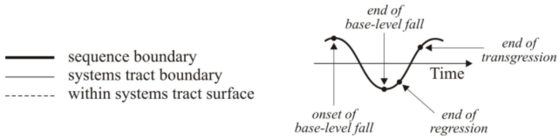

Fig. 2: Timing of systems tracts and sequence boundaries for the sequence models currently in use (Catuneanu, 2006)

The term 'system tract' was first defined by Brown and Fisher (1977) as a linkage of contemporaneous depositional systems, which is a three dimensional assemblage of lithofacies, genetically linked by operative or inferred processes and environment.

Highstand Systems Tract (HST) forms during the late stage of base-level rise where normal regression occurs due to slow rate of base-level rise in comparison to sedimentation rate and depositional trends and stacking patterns are dominated by progradation and aggradation. HST deposits from shoreline to shoreface form good reservoirs.

The Falling Stage Systems Tract (FSST) includes deposits during forced regression of the shoreline typically consisting of shallow and deep water facies and subaerial unconformity in the non-marine part. High density turbidites formed during late stage of forced regression form potential reservoirs.

Lowstand Systems Tract (LST) is deposited during an interval of relative sea-level fall at the offlap break and subsequent slow sea-level rise. Lowstand deposits typically consist of the coarsest sediment fraction of both non-marine and shallow marine sections. Coarser fluvial sediments within fluvial and coastal part form best reservoirs.

Transgressive Systems Tract (TST) is deposited during relative sea-level rise and accommodation volume is increasing faster than rate of sediment supply. It is bounded by the maximum regressive surface (MRS) at the base, and by the maximum flooding surface (MFS) at the top. It consists of mostly topsets along with few clinoforms and is retrogradational resulting in to fining upward sequence in marine and non-marine deposits. Deposits near coast line during TST may hold potential reservoir in the form of backstepping beaches.

In the T/R sequence model Regressive Systems Tract (RST) includes both the strata deposited during shoreline regression (progradational stacking pattern) i.e. HST, FSST and LST sediments (Fig. 2).

Based on basin forming tectonic events and their impact on sedimentation processes, three 1st order sequences have been identified in Cambay Basin. These are Late Cretaceous Passive margin sequence following the Kutch rifting (separation of Madagascar from India) bounded by MI 80 and CI 10 unconformities, Paleocene Rift sequence related to separation of Seychelles from India at K/T boundary bounded by CI 10 / CI 20 unconformities and Early Eocene to Recent Rift Fill sequence with CI 20 unconformity at the base. Six major unconformities/ hiatuses of varying span i.e. at the top of Cretaceous, Paleocene, Early Eocene, Late Eocene, Early Oligocene and Miocene have been identified, which form the basis for identification of 2nd and 3rd order sequences. In the present work two Eocene 2nd order depositional sequences of passive margin viz., 2nd order Early Eocene sequence and 2nd order Middle-Late Eocene sequence have been taken up for detailed T/R sequence analysis (Fig. 3).

1st order Rift Sequence (Paleocene): The sequence relates to breaking up of Seychelles from India at the K / T boundary (Seychelles fragmentation) and relates to synrift phase of the basin evolution, comprising of rift sediments (Olpad Formation, Older Camay Shale). This sequence is bounded by CI 10 and CI 20 unconformities. Towards the base, it unconformably overlies the Late Cretaceous, Deccan Trap volcanics (C I 10). Lower part of this sequence is penetrated only in few wells. Top of sequence is defined by seismic truncations, which are clearly observed on seismic sections throughout the basin, as unconformable contact with the overlying Early Eocene sequence (C I 20). The upper unconformable contact of this sequence represents end of rift phase in Cambay Basin. This sequence is either absent or thinly developed over the paleo highs and is restricted only in fault grabens and fault scraps extending as a piedmont fanglomerate. Lithologically, it is represented by Trap wash, red and grey claystone, grey shale and grey brown sandstone with thin coal beds towards north. Deposition of this unit indicates initiation of basin fill in Cambay Basin.

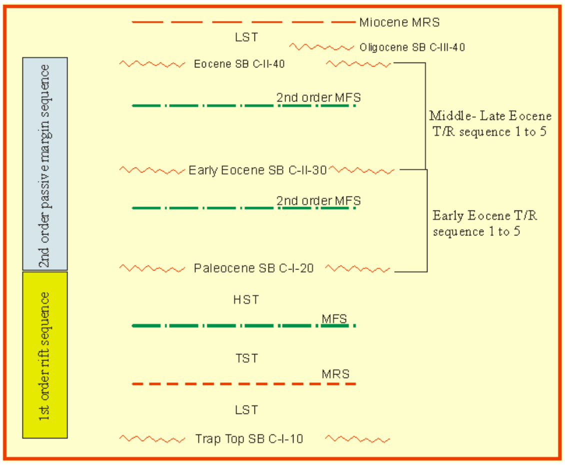

Fig. 3: Sequence stratigraphic framework of Cambay Basin

2nd order passive margin sequence (Early Eocene): The lower and upper contacts of this sequence are marked by unconformities i.e. C I 20 and C II 30, respectively. The lower contact represents end of synrift phase, while the upper contact is represented by a hiatus marked by seismic truncations. Based on faunal and floral evidences along with the lithological attributes, a continental to inner shelf environment has been envisaged for the sediments representing this sequence. The variation in the depositional environment of the sequence from north to south i.e. from continental to intertidal to inner neritic is attributed to basin configuration during Early Eocene. This sequence is subdivided into Transgressive Systems Tract (TST) and Highstand Systems Tracts (HST) based on identification of maximum Flooding Surface (MFS) on well log correlations. The 2nd order MFS corresponds to the Lower Tongue of Kadi Formation (Fig. 4). This tongue represents the most prominent transgression of the southern sea covering the entire Cambay Basin.

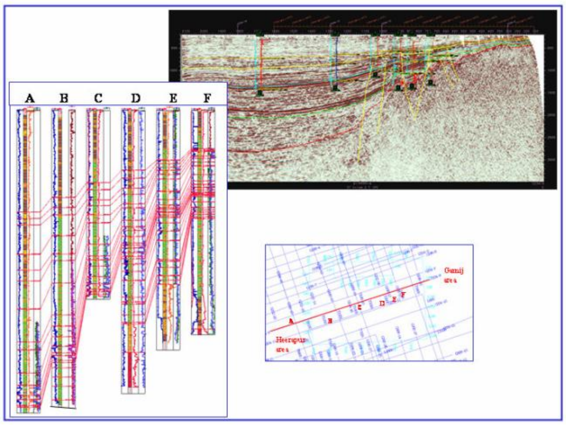

Fig. 4: Calibration of electrolog with seismic passing through Hirapur-Gamij area and correlation of T/R sequence on logs

3rd order sequence (Middle-Late Eocene): The lower and upper contacts are unconformable. The lower contact (C II 30) represents a hiatus of approximately 2Ma duration while the upper unconformity (C II 40) represents Late Eocene – Early Oligocene contact marking major tectonic adjustment. The sequence is subdivided into TST and HST separated by MFS. The MFS corresponds to the Kansari Shale Member of Kalol Formation, which separates the two arenaceous members- lower Sertha and upper Wavel Member.

Discussion

Hydrocarbon rich Cambay Basin has structural and stratigraphic pinch-outs and has complexities in reservoir continuity and structural disposition. Mandhali, Mehsana and Chhatral members of Kadi Formation have good reservoir potential and major pay sands are in Jotana, Sobhasan, Nandasan areas. In the Kalol Formation Nandasan, Becharaji, Lanwa, Balol, Santhal, Sobhasan, North kadi and South Kadi are the major pool areas.

1st order Paleocene rift sequence corresponds to Olpad Formation and Older Cambay Shale. The Paleocene sequence is represented mainly by three facies viz., facies A, B and C. Lower most facies 'A' is dominanly conglomerate with minor alternations of clay, shale and sandstone deposited as alluvial fan. Facies 'B' is dominantly trapwacke with minor alternations of trap conglomerate, sandstone and shale deposited as braided stream deposits. Facies 'C' is mainly claystone and shale with minor siltstone and sandstone alternations deposited in distal aprt of alluvial fan with few channels. Alluvial fan deposits with typical aggradation (lower fluvial energy) and progradation stacking pattern (higher fluvial energy) are observed on electrologs on the upper part of the facies. Paleocene sequence can be divided into three systems tracts viz. lower most and middle facies one as LST and uppermost facies as TST and HST. TST and HST fluvial sediments have good reservoir characteristics.

In the Early Eocene T/R sequence 1, which is the lowermost T/R sequence of the passive margin setup in the Cambay Basin, has lower boundary with Paleocene sequence (C I 20) coincides with the end of synrift phase and the upper contact is at the Maximum Regressive surface (MRS) designated as MRS 15. The sequence represents the first marine transgression of the Early Eocene in Cambay Basin and is absent along the basin margin and thinly developed towards basinal side in the study area. Similarly T/R sequence 2, dominantly consisting of an arenaceous facies with shale and thin sands with thick coal, has more widespread distribution indicating pronounced transgression covering more highlands in the basin. T/R sequence 3 comprises of shale with thin sand in the lower part (TST) and alternation of sandstone and siltstone with grey shales and thick coal in the upper part (RST). The transgression was most widespread in the TST upto the 2nd order MFS which corresponds to Lower Tongue. Tidal channel and tidal flat depositional environment has been inferred for T/R sequence 1 to 3.

Early Eocene T/R sequence 4 and 5 are composed of alternations of sandstone and siltstone separated by thin to thick coal beds and are showing regressive phase deposited during HST. Lower delta plain and inter distributary bay sans/silts are potential reservoirs.

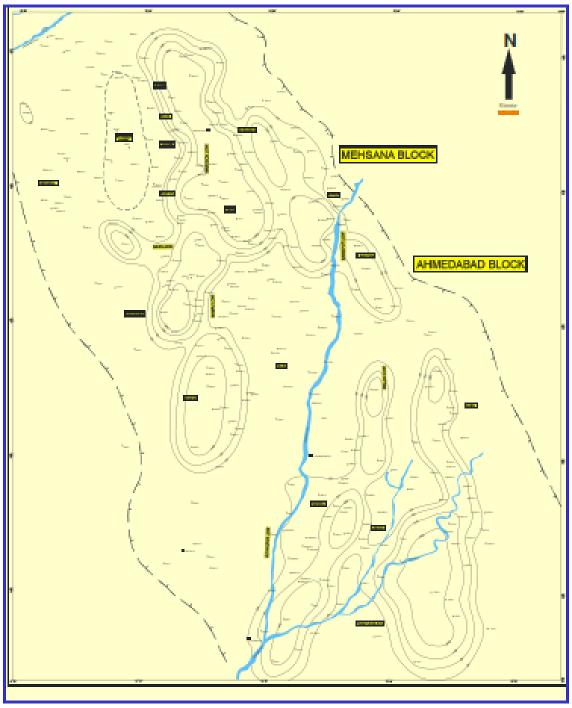

Fig. 5: Reservoir facies map of Early Eocene sequence, North Cambay Basin

Middle–Late Eocene T/R sequence 1, overlying Early Eocene top sequence boundary C II 30, comprises of sand, siltstone, occasional claystone and intervening shale with significant coal represents next transgression in the basin. Similarly, T/R sequence 2 has wide distribution throughout the basin and both the sequences hold potential reservoir of Lutetian stage in the form of Kalol sands deposited as tidal channels. 2nd order MFS corresponds to the Kansari shale. T/R sequence 3 deposited in fully marine set up (HST) is mainly developed as an arenaceous facies with sand and coal in the basinal part. This sequence has deltaic sands in the lower part and shoreface sands in the upper part with good reservoirs in the form of Kalol sands and Limbodra pay. Reservoir facies map of Early Eocene sequence depicting varying thickness in different areas of North Cambay Basin is shown in figure 5. T/R sequence 4 and 5 have foreshore to shore deposits and typically consist of alternations of sandstone, siltstone with shale. T/R sequence 5 corresponds to the Tarapur Shale and basin wide regression is evidenced from prograding shoreline. The potential of T/R sequences 4 and 5 are poor but based on the reservoir thickness and paleogeophrphic setup, the sands of have potential as stratigraphic pinchouts and closures in the study area. Eocene top sequence boundary C II 40 represents end of regressive phase in the area.

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References

Biswas, S.K. (1982) Rift basin in western margin of India with special reference to Kutch Basin and its hydrocarbon prospects. AAPG, v.66(10), pp.1497-1513.

Brown, L.F.Jr. and Fisher, W.L. (1977) Seismic stratigraphic interpretation of depositional systems: examples from Brazilian rift and pull apart basins. In: Payton, C.E. (Ed.) Seismic Stratigraphy- Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists, Memoir 26, pp.213-248.

Catuneanu, O. (2006) Principles of Sequence Stratigraphy. Elsevier publication, 375p.

Embry, A.F. and Johannessen, E.P. (1992) T-R sequence stratigraphy, facies analysis and reservoir distribution in the uppermost Triassic- Lower Jurassic succession, Western Sverdrup Basin, Arctic Canada, In: Arctic geology and petroleum potential (T. O. Vorren et al., Eds.,), pp.121-146, Norwegian Petroleum Society, special publication 2.

Galloway, W.E. (1989) Genetic stratigraphic sequences in basin analysis, I. Architecture and genesis of flooding-surface bounded depositional units. AAPG Bulletin, v.73, pp.125-142.

Miall, A.D. (1995) Whither stratigraphy. Sedimentary Geology, v.100, pp.5-20.

Naqvi, S.M. and Rojers, J.J. (1987) Precambrian geology of India, Oxford, NY.

Pandey, J., Singh, N.P., Krishna, B.R., Sharma, B.R., Sharma, Parekh, A.K. and Nath, S.S. (1993) Lithostratigraphy of Indian Petroliferous Basins– Cambay Basin, KDMIPE, ONGC, Dehradun publication.

Payton, C. (ed.) (1977) Seismic stratigraphy: applications to hydrocarbon exploration: AAPG Memoir 26, 516p.

Posamentier, H.W., Jervey, M.T. and Vail, P.R. (1988) Eustatic controls on clastic deposition I - conceptual framework. In: Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A., and Van Wagoner, J.C. (Eds.) Sea Level Changes - An Integrated Approach. SEPM Spec. Publ., v.42, pp.110-124.

Sloss, L.L., Krumbein, W.C. and Dapples, E.C. (1949) Integrated facies analysis. In: Longwell, C.R. (Ed.) Sedimentary facies in geologic history. Geological Society of America Memoir 39, pp.91-124.