SEQUENCE STRATIGRAPHY OF MIDDLE EOCENE TST IN BROACH-JAMBUSAR BLOCK, CAMBAY BASIN, INDIA

(SYNOPSIS)
Ph.D. THESIS

by

SAPANA JAISWAL

DEPARTMENT OF EARTH SCIENCE
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE – 247 667 (INDIA)

SEPTEMBER, 2019

1. Introduction

The Cambay Basin (fig.1) is a narrow elongated intracratonic rift graben situated in north western part of Indian Peninsula. The Basin consist of several intra basinal uplifted blocks,Saurashtra Craton on the west, Aravalli swell on the northeast and Deccan Craton to the southeast. It extends from north of Sanchor to the south in Cambay Gulf and ultimately open into the Arabian Sea. The Basin has Deccan Trap volcanic rocks as technical basement over which 7 kms (+) thick Cenozoic sediments were deposited. The Basin is divided into two sub-basins namely North Cambay and South Cambay based on their lithostratigraphy and sedimentation pattern. The present study is confined to Broach-Jambusar Block of South Cambay Basin. In this Block, reservoirs within Hazad Member are the major producers of Hydrocarbons. The Hazad Member of Middle Eocene is a TST part of “Middle Eocene to Late Eocene II order sequence”. The Hazad Member, resting over the coeval Younger Cambay Shale, belongs to this 2nd order TST and is bounded by the Y-Marker at the base (unconformity) and by the Kanwa Shale at the top (marking the maximum flooding surface). However, such a TST is characterized by several short term fining-up and coarsening-up successions, within an overall fining up trend. Thus, identification of these high frequency cycles and corresponding sequence stratigraphic surfaces is felt necessary to bring out the changes in sedimentation pattern in the Hazad Member within a high resolution sequence stratigraphic framework.

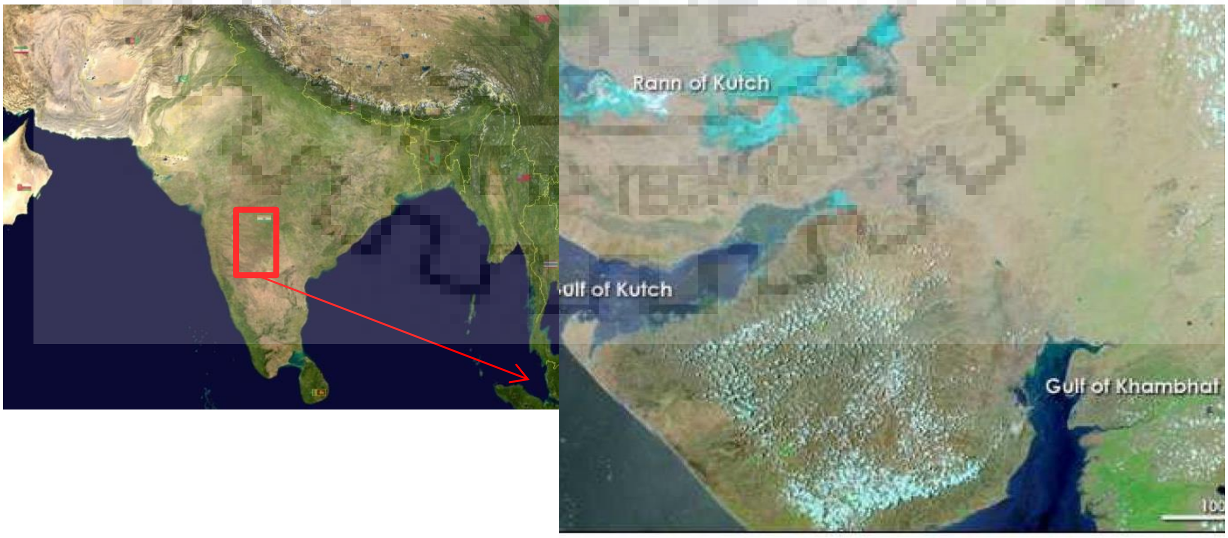

Fig.1 Map showing location of the Cambay Basin

2. Geological Background

The Cambay Basin is subdivided into five major tectonic blocks based on major basement faults which have been named from North to South as (Fig2):

I. Sanchor-Patan Block
II. Mehsana-Ahmedabad Block
III. Tarapur-Cambay Block
IV. Jambusar-Broach Block
V. Narmada-Tapti Block

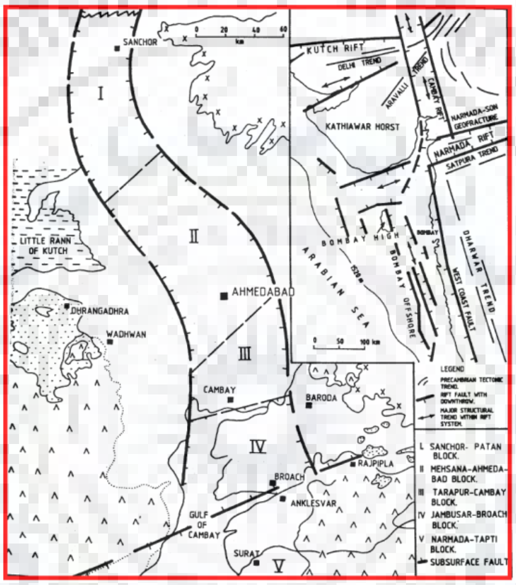

Fig.2 Map showing the block division of the Cambay Basin

The first three blocks correspond to North Cambay Basin and the last two blocks are known as South Cambay Basin. The Mahi River separates both sub-basins for convenience of geological studies. Lithostratigraphically, north and south Cambay basins are different being deposited by two different drainage system i.e. North-South flowing Proto Saraswati river system in North Cambay Basin and East-West flowing Proto Narmada / Proto Dadhar river system in South Cambay Basin.

A detailed account of lithostratigraphic framework (fig.3) of the basin has been documented by Pandey et al., (1993), which establish twenty formations and one group to classify the entire sedimentary record of the basin.

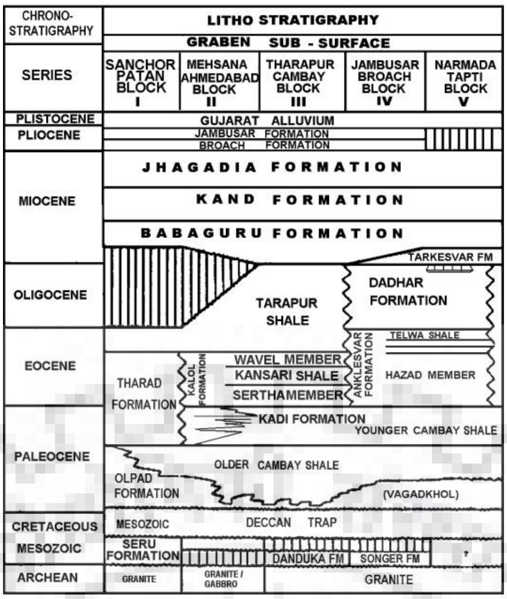

Fig.3 Lithostratigraphy of Cambay Basin

Based on the tectonic evolution of the region the basin developed in three stages:

a. Syn-rift

b. Post-rift sag and

c. Inversion

The present study is confined to Jambusar-Broach Block of South Cambay Basin between Mahi River in north and Tapti River in the south. (fig.4)

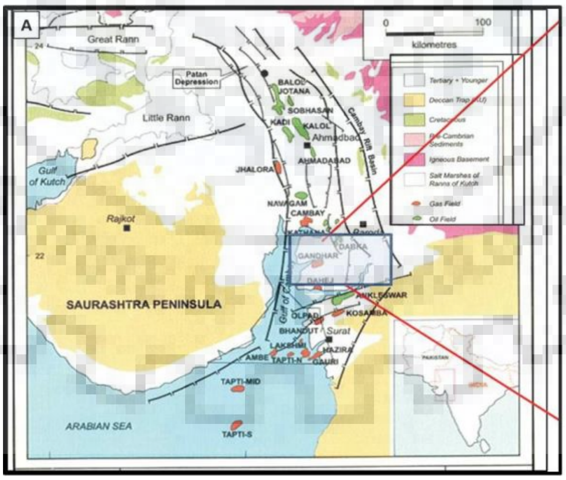

Fig.4 Study area

3. Objective

The depositional model of Hazad reservoirs remained speculative even after about fifty years of exploration and warrants further consideration. The objective of this thesis is identification of high frequency sequences and depositional environments within the Middle Eocene Hazad Member (the 2nd order TST) in the Gandhar - Jambusar area. These lithounits have been explored and exploited as important hydrocarbon reservoirs since decades by ONGC. So, this study will further enhance the understanding of variations in sediment supply and available accommodation within the Hazad Member in a much better way distribution and basin evolution during various stages/units of Middle Eocene TST by well logs and subsurface data analysis (cores/cutting). The study will also focuses on the key elements of petroleum system in the study area.

The objectives of this study are summarised below:

- Facies characterization, sediment dispersal and Process response modeling of Hazad sands to understand tectonics, processes and Basin evolution
- Delineation of the depositional environment and paleogeographic reconstruction through high resolution Sequence Stratigraphy

4. Methodology

This study on facies characterstics and identification of lower order high resolution sequence stratigraphic surfaces is mainly based on available conventional cores and electrolog motifs from different sandstone units of the Hazad Member (average thickness 220 m). Each conventional core is of 5m length with core diameter of 12.7 cm and more than 350m of cores (representing 70 cores from 25 wells) from different sandstone units of the Hazad Member were studied. Basic electrolog data incorporating mainly four conventional logs, viz. Gamma-ray (GR), Resistivity, Neutron and Density logs have been calibrated with lithology and the electrolog motifs were used for regional correlation of different sandstone units present within the Hazad Member from basin margin to interior. The sand thickness of individual parasequence sets and parasequences (different sand units of Hazad) has been measured from electrologs and plotted as sand isolith maps of lower orders in PETREL 2016 software M/S Schlumberger. The cores have been studied in terms of their facies characteristics (Miall, 1980; Walker, 1984; Reading, 1996), megascopic and petrographic analysis to have a clear understanding of the process related facies analysis. These were further supported by regional correlation of electrologs from basin margin to interior and the sand isolith maps prepared for the parasequence sets and parasequences, which reveal spatio-temporal changes in sedimentation pattern and explain the 3-D sand distribution within the Hazad Member.

5. Facies Architecture

The Hazad Member (Middle Eocene) consists of a number of sandstone units separated by intervening marine shales. These shales are greenish grey to pale grey, hard, moderately fissile and bioturbated toward their top. The sandstones are mainly quartz-arenitic in composition, and they generally thin and split basinward (westward), inter-tonguing with the coeval Younger Cambay Shale. In the study area, the 220 m-thick Hazad Member consists of thirteen stacked sandstone units (GS-0 to GS-12) showing similar character. Eastward (landward), the sandstones become progressively better sorted and the intervening shales thin out or disappear, so that the successive units are amalgamated (Fig.5).

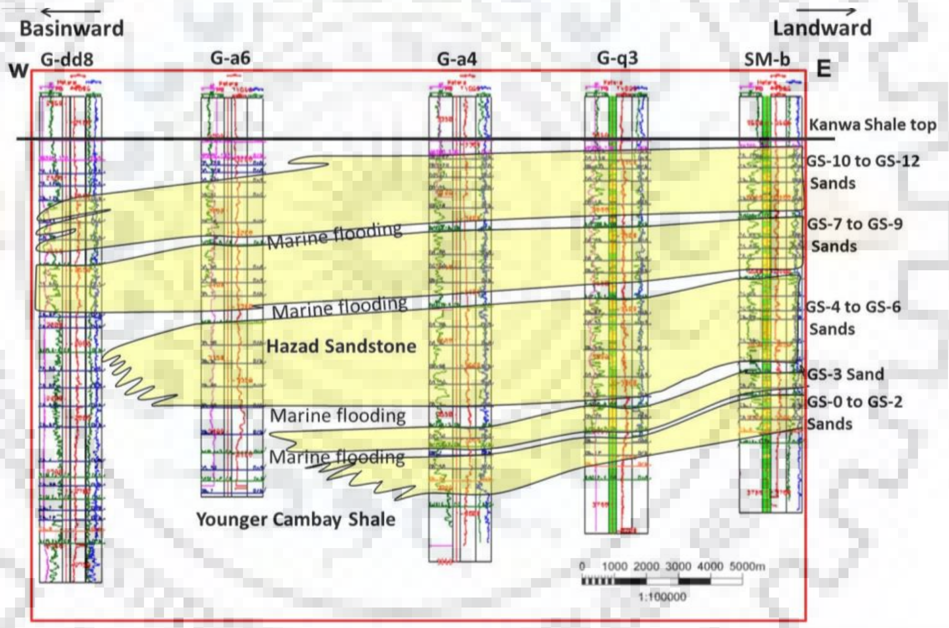

Fig. 5: Correlation of different sandstone units within Hazad Member (GS-0 to GS-12) from basin margin to interior. Note the westward progradation of sandstone units, separated by events of marine flooding and stepped up contact between the younger Cambay Shale with overlying Hazad Member indicating punctuated progradation of sandstones. Also note the degree of progradation is maximum in the middle part of Hazad followed by a back stepping sandstone units (GS-9 to GS-12), indicating a rise of relative sea level.

The Hazad Member is traditionally reported as a deltaic system and each sandstone unit exhibits superposition of four distinct facies associations based on core studies, i.e., (i) sandstone-rich upper delta plain (FA-1) deposits, (ii) sandstone-mudstone heterolithic lower delta plain and delta front (FA-2) deposits (Coleman and Prior,1981), (iii) reddish, silty-shale dominated prodelta (FA-3) deposits and (iv) regionally correlatable, greenish grey shales (FA-4), rich in fossil assemblages of foraminifera and nannoplanktons. The vertical superimposition of different facies displays an overall coarsening-up to fining-up succession (Jaiswal and Bhattacharya, 2018) (Figs. 6 and 7).

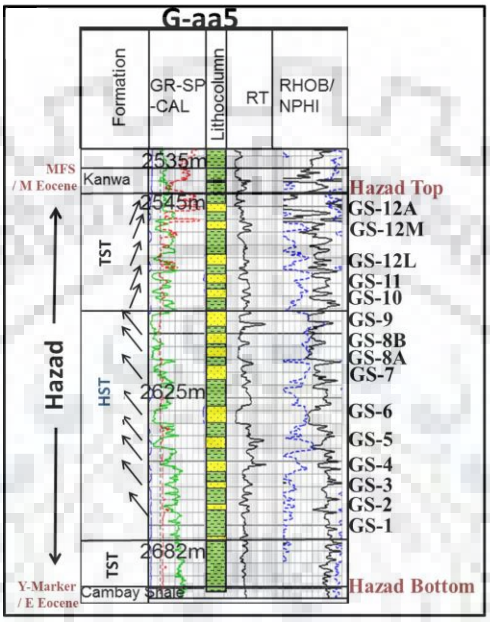

Fig. 6: Key well G-aa5 showing individual sandstone units of the Hazad Member. The coarsening-up eletrolog motifs are marked by arrows

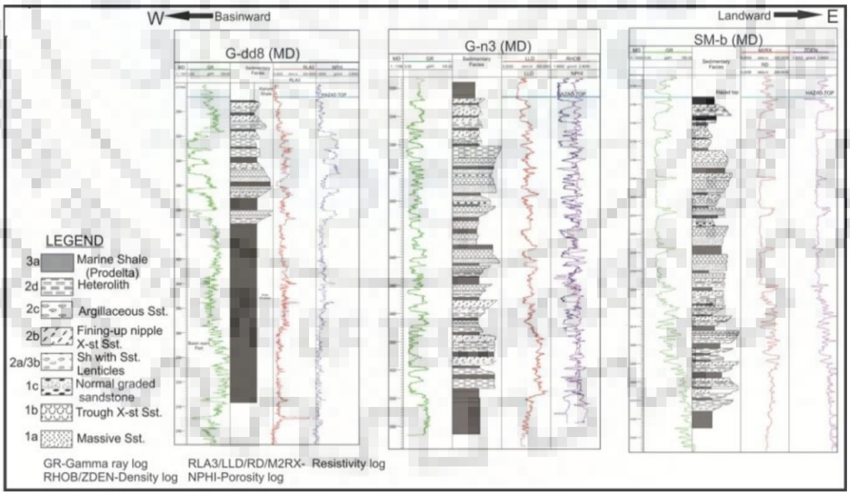

Fig.7: Vertical and lateral distribution of three different facies associations in the Hazad Member resting on younger Cambay Shale in a depositional dip parallel section from basin margin to basin interior. Note recurrence of deeper facies in basin margin indicating events of marine flooding and basinward shift of facies associations indicating progradation. Vertical scale is represented by measured depth (MD) in meters.

6. High frequency Lower Order sequence within Hazad member

The lower order high-frequency (4th or 5th order) sequences are sub-seismic scale and define the purpose of high-resolution sequence stratigraphy. In the present work, the term parasequence-set and parasequence is used to designate the cycles of 4th and 5th-order small-scale high-frequency sequences (Catuneanu and Zecchin, 2013). Parasequences represents 5th order units separated by transgressive units (marine flooding events) and parasequence-sets are 4th order units bounded by increased transgressive events (maximum flooding events).

Based on basin formative tectonic event and their impact on sedimentation processes three first order sequences viz, Late Cretaceous passive margin sequence followed to Kutch rifting (separation of Madagascar from India), Paleocene rift sequence related to separation of Seychelles from India starting at K/T boundary and Early Eocene to Recent rift fills passive sequence (Parakh et al., 2007).

Based on basin modifying tectonics of the basin, four 2nd order sequences are recognised and mapped in Early Eocene to recent 1st order rift fill passive margin sequence viz. Early Eocene, Middle-Late Eocene, Early Oligocene to Miocene and Pliocene-Recent bounded by unconformities.

In Early Oligocene to Miocene 2nd order sequence two 3rd order sequences have been mapped viz Early Oligocene sequence and Miocene sequence bounded by unconformities.

The Hazad Member of Middle Eocene age is a TST part of 2nd order sequence “Middle Eocene to Late Eocene sequence”. It unconformably overlies the Early Eocene sequence and underlies the Maximum Flooding Surface and relates to Late Eocene uplift. The 2nd order TST has been further subdivided into three major 3rd order systems tracts. The bottom part (~30m-thick) of the Hazad Member is devoid of sandstone and exhibits a fining up trend in log character with maximum gamma value at top and represents a TST with MFS at its top. The successive sandstone units (GS-0 to GS-9) exhibit a coarsening up trend constituting a highstand systems tract (HST), (~140m-thick). The overlying sandstone units (GS-10 to GS-12) with fining up log motif continuing to the Kanwa Shale at top represents the top most TST (~50m-thick).

Six such maximum flooding surfaces has been marked and correlated in the study area which represents genetically related stratal pattern of next lower most order (the 4^{th} order) throughout the succession. Towards basin each sand units of

Hazad Member grades to marine shales (i.e. Younger Cambay Shale) and denotes the progradational limit of each sand unit (see in wells SM-b and G-dd8 in Fig.7). The next lower most orders (5th order) represent the marine flooding events separating the coarsening up parasequences unlike the longer MFS events that separates the parasequence sets described earlier. In the landward well SM-b the individual parasequences representing GS-0, GS-1A, GS-1, GS-2 together constitutes a parasequence sets (Fig. 8). The overlying parasequence set constitute GS-3A and GS-3B sands. The duration of marine flooding represented by shales separating individual parasequences must have lower from those separating the parasequences sets and thus represents the lowest order sequence (5th order). The thickness of shales separating the parasequnces (of 5th order) is also less as compare to those separating the parasequence sets (of 4th order).

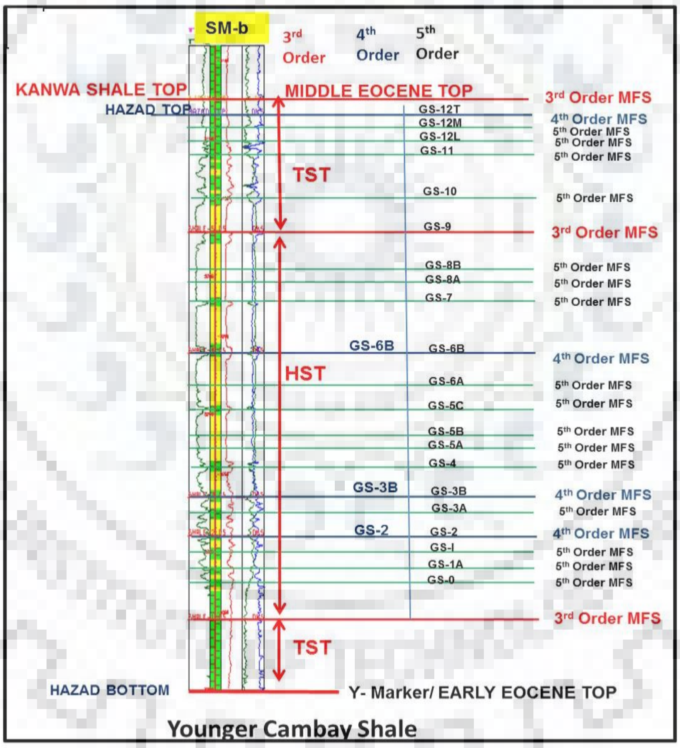

Fig.8 Key basin margin well SM-b showing 3rd, 4th and 5th order sequence stratigraphic elements. Note that the Middle Eocene Hazad Member, resting over the Younger Cambay Shale, is bounded by Y-marker (unconformity) and Kanwa Shale top (maximum flooding surface) and belongs to a 2nd order transgressive systems tract (TST). Note the progradational (coarsening-up) to aggradational eletrolog motifs of the sandstone units up to GS-9 followed by retrogradational (fining-up) trends

7. Key elements of Petroleum System Modeling

Petroleum system encompasses a pod of active source rock related to generation of oil and gas and includes all essential elements and processes needed for oil and gas accumulation. The essential elements of a petroleum system are source rock, reservoir rock, seal rock and overburden rock. The processes include trap formation and generation-migration-accumulation of petroleum. All essential elements must be placed in time and space such that the processes required forming a petroleum accumulation can occur (Magoon and Dow., 1994).

In the study area, the principle source intervals are the deltaic, lagoonal and shallow marine anoxic shales of the Upper Paleocene to Middle Eocene Cambay Formation, with lesser inputs from lacustrine shales of the Paleocene Olpad Formation. Principle reservoir interval consists of the fluvio-deltaic Ankleshwar Formation, primarily the Hazad Member with a lesser degree the Ardol Member, which contains 42% of the oil and 51% of the gas reserves in the basin.

In order to understand the key factors that control the petroleum systems of the study area Petroleum Systems Modeling study have been carried out.

The present study has been undertaken using high resolution static model with facies reconstructed following sequence stratigraphic approach with the objective of improved understanding of hydrocarbon fairways. Facies maps have been generated based on the high resolution sequence stratigraphic analysis for the 5th order parasequences of Middle Eocene TST (Hazad Sands) and incorporated in the static model used for petroleum systems modeling.

8. Disscussion

Sedimentation and sequence building pattern of the Middle Eocene Transgressive Systems Tract (TST) that belongs to the Hazad Member of the Ankleswar Formation of Cambay Basin, India constitutes the core theme of this thesis. The thesis has three main parts; the first part dwells on local geology and paleodepositional environment from detailed facies analysis of Hazad Member from subsurface data. The second part comprises Facies analysis from different conventional cores taken from Hazad Member along with its petrographic studies XRD and SEM analysis to know the clay mineralogy and diagenetic. The third part addresses a high resolution sequence stratigraphy of the Middle Eocene 2nd order TST that enabled the subtle depositional changes within the Hazad Member.

The Hazad Member is entirely siliciclastic and bears imprints of marine and fluvial processes. It belongs to a 2nd order TST owing to increase in accomodation space. So far, the Hazad Member (dominantly 13 sandstone units, designated as GS-0 to GS-12) has been interpreted as prograding deltaic depositional systems with development of tidal flats near the top (Pande et al., 1989; Aswal et al., 2013). These sediments were carried out by proto-Dadhar/ proto-Narmada river systems from the east and northeast direction as interpreted from the sand thickness maps prepared by earlier worker (Parakh et al., 2013). However, these studies were not substantiated with adequate supportive facies analysis and other traditional sedimentological attributes. Present work documents three major facies associations, viz., (i) sandstone-rich upper delta plain deposits, (ii) sandstone-mudstone heterolithic lower delta plain deposits, and (iii) shale-dominated prodelta deposits, in an overall coarsening-up to fining-up succession.

The lithofacies and their association indicate sedimentation took place in laterally adjacent sub-environments, viz. upper delta plain, lower delta plain and pro-delta. The lower delta plain sediments record cyclic stacking of coarser and finer sedimentary facies successions, accumulated under two major depositional systems, viz. (i) Subtidal depositional system, characterized by sandstone-dominated facies succession and (ii) Intertidal depositional system, represented by mudstone-rich heterolithic facies succession. Facies architecture reveals basinward prograding succession of prodeltaic sediments in the western part, lower delta plain with subtidal-intertidal sedimentation in the central part and fluvially-dominated upper delta plain deposits in the eastern part. Stacked coarsening-up successions in the lower part followed by fining-up successions at the upper part of the Hazad Member manifest a transgression following the initial regression during the Middle Eocene. As a whole, therefore, the coarsening-up to fining-up sedimentary succession of the Hazad Member, with progradational deltaic lobes in the lower part followed up by predominant tidal sedimentary succession in the upper part, signifies a regressive to transgressive shift of the shoreline. Such encroachment of the sea towards land in the top part of Hazad is caused by significant change in the base level and accommodation in response to change in sea level and/or basinal tectonisms (subsidence).

Hazad Member consists of 13 sandstone units (GS-0 to GS-12), separated by intervening marine shales, representing progradational pulses within an overall fining-up 2^{nd} order transgressive systems tract (TST). The sandstone is mainly quartzarenitic in composition, and it generally thins and splits basinward (westward), intertonguing with the coeval Younger Cambay Shale. The T-R succession of Cambay Basin, particularly the succession that belongs to a 2^{nd} Order TST of Hazad Member is analysed in the light of high-resolution sequence stratigraphy to identify the 3^{rd} order (TST/HST/TST), 4^{th} order (parasequence sets) and 5^{th} order (parasequences) events, based on facies associations, trends of electrolog motifs and stratal packages. High resolution sequence stratigraphic analysis based on core and electrolog data subdivides the 2^{nd} order TST into three 3^{rd} order systems tracts, namely, (i) basal shaly transgressive systems tract (TST), followed by (ii) highstand systems tract (HST) incorporating four intervening parasequence-sets (GS-0 to GS-2, GS-3, GS-4 to GS-6 and GS-7 to GS-9) separated by flooding surfaces of 4^{th} order, and (iii) transgressive systems tract (TST) at the top consisting of parasequence-sets (GS-10 to GS-12) capped by Kanwa Shale as maximum flooding surface (MFS). The amalgamated sands of 3^{rd} order sequences in the landward part are splitted basinward forming six coarsening up parasequence-sets of 4^{th} order, which are further subdivided into 21 parasequences of 5^{th} order, separated by minor events of marine flooding. The depositional model and the paleogeographic maps using 3^{rd}, 4^{th} and 5^{th} order sequence elements and parasequences reveal that - (i) minimal sand supply at the beginning of 3^{rd} order HST as evident from isolated and redistributed sand bodies due to tidal influence from south, and (ii) significant increase in fluvial sand supply thereafter by proto-Narmada and proto-Dadhar river systems leading to progradation till the end of HST (Gandhar Sand units GS-0 to GS-9) resulted constructive delta building till GS-9, (iii) The topmost transgressive parasequence sets constituting GS-10 to GS-12 mark landward retreat due to a paucity of sand supply and/or a rise in relative sea-level, which resulted back-stepping of paleo-shoreline and development of estuaries over the initial deltaic setting.

9. Conclusion

- The present study systematically documents tidalites from the Middle Eocene Hazad Member and highlights important aspects of tide-led sedimentation in the Cambay Basin.

- Facies succession bearing various tidalites (tidal bundles, tidal beddings and tidal rhythmites) signifies sedimentation in a subtidal to intertidal depositional system, with rapid fluctuation in depositional conditions.
- The study provides documentation of lower order, high frequency sequence stratigraphic elements within the Middle Eocene in the frame of shifting depositional settings and paleogeography. The Hazad Member is characterized by 13 sandstone units (GS-0 to GS-12), representing progradational pulses within an overall fining-up 2nd order transgressive systems tract (TST).
- This succession is analysed in the light of high-resolution sequence stratigraphy to identify 3rd order (TST/HST/TST), 4th order (parasequence sets) and 5th order (parasequences) units, based on facies associations, trends of electrolog motifs and stratal packages.

Reference

1. Aswal, H.S., Yadava, U.N., Biswas, S., Grover, R., Nayak, K.K., Singh, S., Prathimon, P.T., Rana, P.B., 2013. Lithobiostratigraphic Correlation and Paleoenvironment of Paleogene Pays in Eastern Part of Jambusar – Broach Block Cambay Basin. Unpublished ONGC report. 10th Biennial International Conference and Exposition, Kochi, 170, 1–11.
2. Magoon, B., Dow, W. G., 1994. The petroleum system from source to trap. AAPG Memoir, 60.
3. Catuneanu, O. and Zecchin, M., 2013. High-resolution sequence stratigraphy of clastic shelves II: Controls on sequence development, Marine and Petroleum Geology 39 (2013) 26-38.
4. Jaiswal, S., Bhattacharya, B., 2018. Characterization of middle Eocene tide-influenced delta: a study from core samples of Hazad Member, Ankleshwar Formation, South Cambay Basin, India. J. Earth Syst. Sci.
5. Miall, A.D., 1980. Cyclicity and the facies model concept in fluvial deposits. Bull. Can. Petrol. Geol. 14, 337–381.
6. Pande, A.N., Bhattacharya, S.K., Chaudhury, C.L., Upadhyay, H., Sharma, D.C., 1989. Environmental Reconstruction and Depositional Modelling of the Hazad Pay Sand in Gandhar Field Part II. Unpublished ONGC Report.
7. Parakh, A.K., Shau, S.K., Prakash, A., Negi, A., Pillai, S., Aswal, H.S., Srivastava, H.S., Niranjan, N., 2007. Sequence Stratigraphic Frame Work Cambay Basin. Unpublished report. ONGC, WON, Baroda.
8. Parakh, A.K., Sinha, D.K., Ahmed, A., Brahma, K.C., Prusty, S.K., Hussaini, S., Shridhar, K.N., 2013. Depositional Model and Facies Distribution of Hazad Sands, Narmada Block and Integration with Broach Block, Cambay Basin. Unpublished ONGC Report. pp. 58.
9. Reading, H., 1996. Sedimentary Environments: Processes, Facies and Stratigraphy, third ed. Wiley Blackwell, pp. 704.
10. Walker, R.G., 1984. Facies sequences and facies models. Geol. Assoc. Can. 317.