PaperID **AU386**

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Reservoir Sedimentology, Sequence Stratigraphy and Depositional Model of Oligocene Clastics in C-39 area, Tapti- Daman Block, Western Offshore Basin

Abstract

Sedimentological and biostratigraphic studies of Oligocene clastics (Daman and Mahuva formations) of C-39 area in Tapti- Daman block have been carried out to understand the reservoir sedimentology, sequence stratigraphy and depositional model. These sediments are interpreted to represent three systems tract in response to changing base level.

a)Early Oligocene: TST-HST (deposited during late rise normal regression).
b)Late Oligocene: FSST (deposited due to forced regression).
c)Upper part of Late Oligocene: LST (deposited during early rise normal regression).

Within the TST-HST of Early Oligocene, the bottom most mapped lithofacies package-1 (LP1) was deposited in a barrier bar to offshore bar setup. The facies above this (LP2) has limited lateral extent (isolated sand bodies) and is interpreted to be deposited in lagoonal backshore environment. The facies LP3 represents tidal sand ridges parallel to paleo-slope whereas the facies LP4 was deposited as prograding tide dominated delta. The reservoir characters are best developed in barrier bars (parallel to paleo shoreline in N-S direction of the studied area) and delta (parallel to depositional slope i.e N-E to S-W direction), where the sands exhibit good porosity and the geometry of deposits assures extensive lateral continuity. The sediments deposited due to forced regression during Late Oligocene are dominantly incised valley fill (IVF). However, shoreface sands are observed towards basinal side. The reservoir characters of IVF are poor to moderate on account of their occurrences as pinchouts and presence of amalgamated lithofacies. However the sands with linear geometry parallel to depositional slope show fairly good connectivity. The shoreface sands are only developed towards the basinal side and that too in the upper part of Late Oligocene (LP 7) and characterized by medium to fine grained, fairly sorted sandstone. Sand geometry of these sands generally has extension parallel to paleo-shoreline. The reservoir characters are moderate to good for these sediments with good prospects. Upper most part of Late Oligocene sediments representing LST is widespread across the studied area. These sands are mainly IVF sands oriented parallel to depositional slope. The overlying Miocene sediments are dominantly argillaceous and show a fining up sequence indicating a transgressive regime. The dominant clay mineral in these sediments is kaolinite, however presence of chlorite, illite and smectite in minor to trace amount is observed. Most of these clays are authigenic and have an adverse bearing on reservoir properties. The present study facilitates mapping of Oligocene sediments in time and space for understanding sand geometry and reservoir connectivity for exploration leads thereby indicating development of best reservoirs in the Early Oligocene barrier bar sands of Mahuva Formation.

Introduction

The Tapti-Daman field in the north-northwest (NNW) part of Mumbai offshore Basin, comprises of two large structural culmination- North Tapti and South Tapti. This area is a predominantly clastic sub basin where lower most stratigraphic unit (Paleocene-Eocene, Panna Formation) is the main source facies. The Oligocene succession comprising Mahuva and Daman clastics is one of the established petroleum plays. In spite of good well control and production history, the sand geometry and continuity of reservoir character of these sediments is less understood. The present work is focused on understanding the sedimentological attributes, reservoir characteristics and depositional processes in northern part of Tapti-Daman block in and around C-39 areas (Fig. 1). The study incorporates megascopy, microfacies analysis

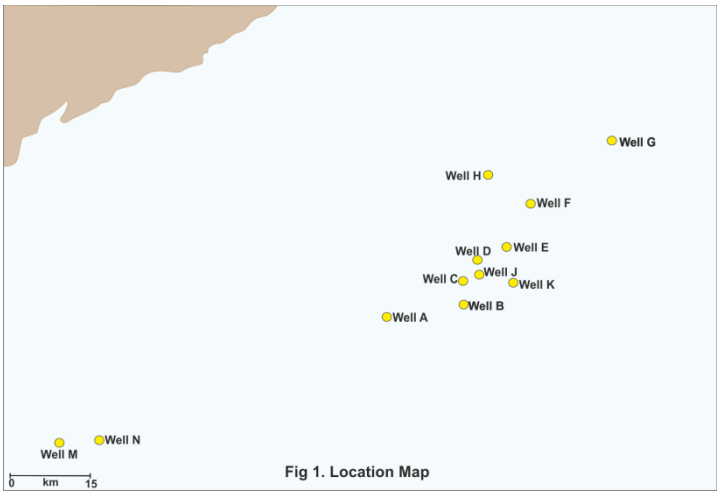

Fig 1. Location Map

and diagenetic studies for firming up the depositional environment for reservoir sand geometry and reservoircharacterization.

Methodology

The scope of work includes detailed description of sedimentological attributes including litho-microfacies, textural characteristics, sedimentary structures and SCAL (XRD and SEM analysis) of the available cores from wells drilled in the studied structures. Samples from twenty conventional cores of six well were used for the study of sedimentological attributes. For biostratigraphic studies, cutting samples have been examined to study the foraminiferal assemblages to infer age boundaries, hiatuses, environment of deposition and paleobathymetry. In case of absence of index fauna or poor sample control, help of electrolog correlation with nearby wells have been taken up for marking the age boundaries.

Observations

Mahuva formation (Early Oligocene):

The Early Oligocene succession is represented dominantly by shale and sandstone with siltstones and some coal laminae. Sideritic claystone and silty shales are also observed. However in well F few limestone beds are also present. As most wells do not cover the entire succession the study is limited to drilled depth.

The sedimentary succession shows an overall aggradational to fining up sequence suggesting deposition in a transgressive to late rise normal regressive (HST) regime. The sand bodies that punctuate the shale at certain intervals are dominantly fine to medium grained and moderately- well sorted. The major sedimentary features are massive sandstone, cross beddings, wavy laminations and bioturbation. Siderite is present as nodules and cement at places. Carbonaceous matter is also observed. The porosity in these sands is good to moderately good demonstrating good reservoir potential. The dominant clay minerals in sands are kaolinite, with subordinate chlorite (ranging from traces to minor amount). The occurrence of clay minerals follows no specific distribution pattern with respect to hydrocarbon distribution and sedimentary process.

Biostratigraphic studies reveal presence of Early Oligocene diagnostic foraminifera. The foraminiferal assemblage consists of both larger and smaller benthic foraminifera with less frequency and diversity. Paleobathymetry of the studied section show that basin becomes deeper in and around wells M and N as compared to the wells of C-39 structure. Presence of planktonic foraminifera, along with benthic foraminifera in the bottommost part of Early Oligocene section in wells M and N suggests paleobathymetry in the range of 20-40m and 50-80m, respectively. In both the wells, paleobathymetry decreases in the upper part in the range of 10-20m. Further drop in paleobathymetry to 5-10m has been recorded in the uppermost part of well M, whereas 10-20m paleobathymetry prevailed in the area of well N. Wells A, C, D and B which lie northeast of M and N, have penetrated 115m(+), 339m(+), 335m(+) and 231m(+) thick Early Oligocene, respectively. Here Early Oligocene succession is represented by clastics (composed predominantly of shale with occasional sandstone and siltstone beds at places and rare occurrence of coal) with paleobathymetry ranges from 5m to 20m which attained maximum (~20m) in the well B.

Daman Formation (Late Oligocene):

The Late Oligocene sediments of Daman Formation are dominantly clastic (siltsone, shale and sandstone). Coal is conspicuously present in wells like D, B and I. In few wells (i.e J, A and H) conglomeratic sediments are also observed.

The sandstones are massive, medium to coarse, poorly sorted often with intercalations of shale, sideritic nodules with porosity ranging from good to poor. The sandstones are intensely to moderately bioturbated. At few places sandstone exhibit faint parallel to inclined bedding. The sandstone is rarely fossiliferous (except CC-9 of A and CC-1 of K). The shales are nodular, bioturabated (seen as sand irregular lenses) and at places carbonaceous and sidertic. At places the lithology is highly amalgamated showing irregular lenses and clasts of sandstone, shale, sideritic sandstone and siltstone.

Biostratigraphic studies indicate absence of age diagnostic foraminifera within the clastic section of Daman formation and the Late Oligocene age is assigned on the basis of stratigraphic superposition as it is underlain and overlain by Early Oligocene and Early Miocene sections, respectively.

Sequence stratigraphy and depositional model

Based on sedimentological attributes, correlation of wire line logs and local tectonics, the Oligocene sediments have been inferred to be deposited by three major events of base level changes. They are:

1. Transgression to Late rise normal regression (HST): Early Oligocene (LP 1 to LP 3)
2. Forced regression (FSST): Late Oligocene (LP 4 to LP 7)
3. Forced regression (FSST) to Early rise normal regression (LST): Late Oligocene (LP 8)

To understand the areal facies distribution and sand geometry and reservoir characteristics deposited by the above processes, two correlation profiles have been prepared across the area passing through 12 wells. Profile1 is NE-SW correlation passing through wells P, G, E, D, C and A (Fig. 2). The second S-NE profile, oblique to earlier one passes through wells I, D, J and D (Fig. 3). The profiles show variable stratal thickness of Oligocene (for both Daman and Mahuva) from NE to SW down slope from landward to basinal part).
The detailed litho-biostratigraphic studies leads to the identification three major depositional regimes which are discussed below.

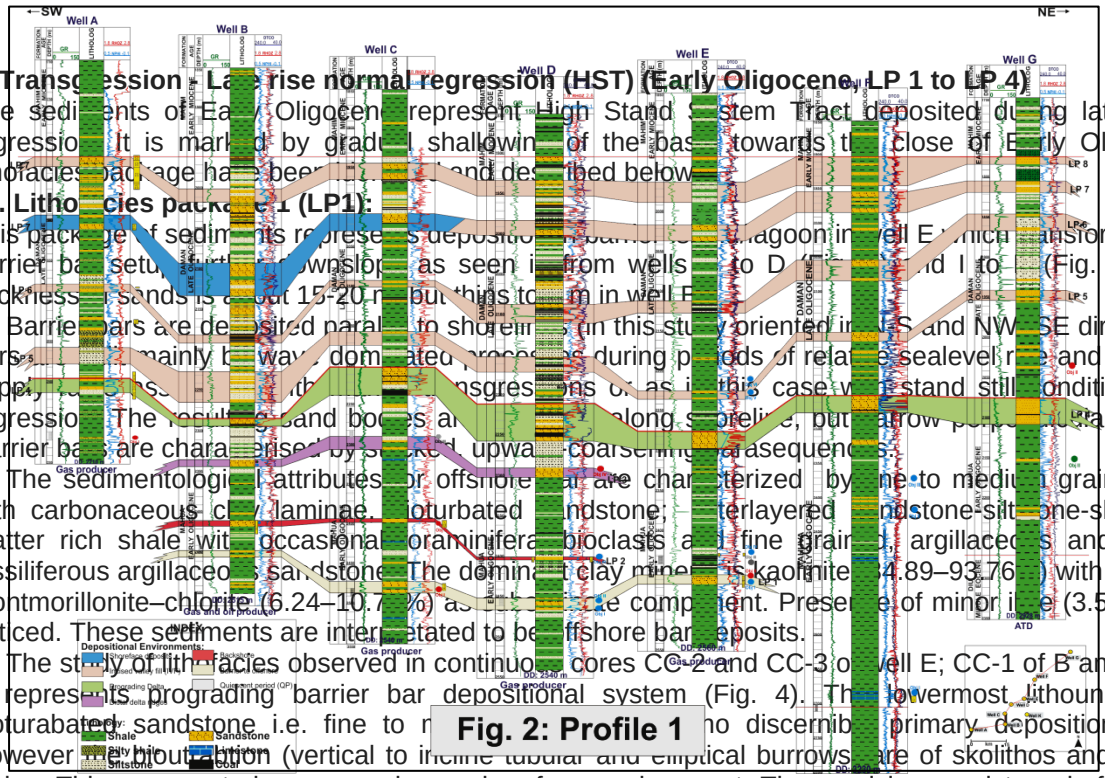

Fig. 2: Profile 1

1. Transgression – Late rise normal regression (HST) (Early Oligocene, LP 1 to LP 4)

The sediments of Early Oligocene represent High Stand System Tract deposited during late rise normal regression. It is marked by gradual shallowing of the basin towards the close of Early Oligocene. Four lithofacies package have been identified and described below.

1a. Lithofacies package 1 (LP1):

This package of sediments represents deposition in barrier bar to lagoon in well E which transforms to offshore barrier bar setup with downslope as seen in from wells D to C (Fig. 2) and I to J (Fig. 3). The gross thickness of sands is about 15-20 m but thins to 5 m in well F.

Barrier bars are deposited parallel to shoreline (in this study oriented in E-S and NW-SE direction). These bars are mainly by wave dominated processes during periods of relative sealevel rise and low sediment-supply conditions of transgressions or as in this case when stand still conditions of normal regression. The reservoir sand bodies are elongated along shoreline, but narrow perpendicular to this trend. Barrier bars are characterised by stacked, upward coarsening parasequences.

The sedimentological attributes for offshore bar are characterized by fine to medium grained, burrowed with carbonaceous clay laminae. Bioturbated sandstone; interlayered sandstone-siltstone-shale, organic matter rich shale with occasional foraminifera bioclasts and fine grained, argillaceous and sideritic and fossiliferous argillaceous sandstone. The dominant clay mineral is kaolinite (84.89–93.76%) with mixed layer of montmorillonite–chlorite (6.24–10.7%) as subordinate component. Presence of minor illite (3.50%) has been noticed. These sediments are interpretated to be offshore bar deposits.

The study of lithofacies observed in continuous cores CC-2 and CC-3 of well E; CC-1 of B and CC-1 of well B represents prograding barrier bar depositional system (Fig. 4). The lowermost lithounit is intensely bioturabated sandstone i.e. fine to medium no discernible primary depositional structures. However the bioturbation (vertical to inclined tubular and elliptical burrows are of skolithos and thalosinoides facies. This represents low energy lower shoreface environment. The overlying sandstone is fine to medium and medium to fine grained and moderately- well sorted and clean with presence of carbonaceous matter and sideritic nodules. The major sedimentary features are massive sandstone to distinct cross bedded sandstone. The clay mineral is dominantly kaolinite and chlorite with traces of montmorillinite. These sands were deposited in high energy upper shoreface to foreshore environment.

The sands offer good porosity and potential reservoir characters due to their clean and well sorted nature. The uppermost unit is bioturabated and carbonaceous shale representing a backshore environment.

1b. Lithofacies package 2 (LP 2):

This sedimentary package was deposited in lagoonal environment of backshore setup. It has limited extent observed from well D to well C (profile 1) and I to J (profile 2). The sand layer is less than 5m except is well J where it is about 15-20 m thick. Sedimentary attributes for CC-1 of well C; CC-3 of well J; CC-1 of well B (Fig. 5) is represented by fine to medium grained bioturbated sand with thin coal and shale laminations, sideritic claystone, laminated siltstone and shale and fine grained argillaceous sandstone. Sedimentary features are wave lamination, lenticular bedding with burrows and foraminifer/ shell fragments. The facies in well C show dominant kaolinite (82.86 – 87.16%) with subequal proportion of illite (5.46-8.89%) and mixed layer clays of montmorillonite and chlorite (4.44-8.85%) whereas in well D the kaolinite (77.50-100%) occurs as a major component with minor chlorite (0.00-14.05 %) and illite (0.00-12.13%). The sand in this lithofacies exhibits good to moderate reservoir potential due to presence of moderate porosity.

1c. Lithofacies package 3 (LP 3):

This facies represent distal delta ridges oriented along NE-SW direction. It extends from well G in NE to well B in SW and well H in N to well L in S. The lithology is medium to coarse grained, moderately sorted and carbonaceous sandstone. No core data is available for this sedimentary package.

1d. Lithofacies package 4 (LP 4):

This facies represents a prograding tide dominated delta. It extends from well G in NE to well A in SW and well H in N to well L. The sand is about 30-35 m thick on average, but gradually decreases downslope to 10 m (toward SW and S). Reservoirs are deposited primarily as sand-ridges or bars and in tidal channels parallel to slope. Sands are fine to medium grained moderately sorted and calcareous towards south (well D and well K) and coarse to medium and medium to fine grained, poorly sorted, calcareous, sideritic and fossiliferous (Fig. 6) towards SW (well A).

7.2 Forced regression (FSST) (Late Oligocene, LP 5 to LP 7)

The Late Oligocene sediments of Daman formation are products of forced regression representing falling stage system tract and consists dominantly of incised valley fill (IVF) and shoreface deposits. Major part of Late Oligocene section in well M experienced deposition under very shallow marine condition with paleobathymetry

in the range of 2-5m. Towards the upper part, gradual rise in paleobathymetry in the range of 10-15m was observed. Late Oligocene sedimentation began in well N under very shallow marine condition where the paleobathymetry was in the range of 2-5m. The middle part of the succession at basinal area experienced a sharp rise in paleobathymetry in the range of 40-50m. A subsequent fall in paleobathymetry in the range of 2-5m has been recorded towards the upper part of the succession. Thus during this period studied area underwent frequent fluctuations in the bathymetry due to tectonic activities.

The facies are stacked into a number of cycles of 10 to 30m thickness showing mixed fining upward up, blocky fining upward and coarsening up successions. Each cycle records different processes and hydrodynamic energy. These cycles are genetically related to active tectonics with high sediment influx and rapid deposition.

In a vertical profile Daman sediments show five lithofacies packages represented by coarsening up and blocky fining up cycles. This phenomenon is commonly observed in all the wells with variations in relative thicknesses and nature of cycles. The sedimentary processes associated with these cycles are dominantly incised valley fill / shallow channels and prograding shoreface sands.

Lithofacies package 5 (LP 5):

This package represents beginning of first mapped major forced regression event in the studied area extending from well G to well A with gradual increase in stratal thickness towards SW.

The sedimentological attributes for this package are characterized by fine to medium grained, moderately sorted sandstone. Also poorly lithified polymictic paraconglomerate (Fig 7) observed in CC-1 of well J ascertain these sediments to be IVF deposits. Towards south (well K) the sandstone is fine to medium, coarse at places, fossiliferous with few bioturbation. The log show fining to faint blocky motif. The reservoir characters are moderate for such sands and have linear sand geometry parallel to depositional slope.

Lithofacies package 6 (LP 6):

This lithopack also represents IVF. The sedimentological attributes are medium to coarse (well J) and fine to very fine (well A, well C), moderately-well sorted sandstones. The logs commonly show fining up to blocky nature. The reservoir characteristics are good to moderate and sands have linear geometry parallel to depositional dip.

Lithofacies package 7(LP 7):

This sedimentary package is represented by IVF that extend upto well D (in profile 1 and 2) and further downslope in wells C to well A of profile 1 and well J to well L of profile 2 transform to shoreface deposits (Fig. 8). The IVF deposits are characterized by fine to medium and moderately sorted sandstone showing fining up log motifs. The shoreface sands are fine to medium and fine to coarse, intensely bioturabated and feebly calcareous to non-calcareous. The logs for these sands are coarsening up to blocky in nature.

7.3 Early rise normal regression (LST): Late Oligocene

The uppermost portion of experienced a gradual rise in paleobathymetry (10-15m) and increased sediment supply thus leading to early rise normal regression. It resulted into progradtion and deposition of IVF sediments.

Lithofacies package 8 (LP 8):

This sedimentary package is dominantly IVF observed in all wells of profile 1 and 2. The sedimentological attributes for this package are characterized by medium to coarse to very coarse grained and fine to medium, moderately well sorted and calcareous sandstone. The thickness of sand layers is variable ranging from 5 to 20m. The sand geometry is parallel to depositional slope and log motifs are manifested by box type to fining up features. The reservoir characters are moderate for such sands. The dominant clay mineral is kaolinite with some chlorite.

Conclusion

The Early Oligocene sediments representing Mahuva Formation are dominantly shales with few bodies of sand and silt and minor coal whereas Late Oligocene sediments of Daman Formation are frequently sand and silt rich. Also coal bands are abundantly present in wells like D, B and I. Oligocene sediments are interpreted to represent following three systems tract formed in response to changing baselevel.

1. Early Oligocene: TST-HST (deposited during late rise normal regression).
2. Late Oligocene: FSST (deposited due to forced regression).
3. Upper part of Late Oligocene: LST (deposited during early rise normal regression).

In Early Oligocene bottom most mapped facies (LP1) was deposited in a barrier bar (well E) to offshore bar (well D, C, J, K and B) setup and sand geometry is parallel to paleo shoreline. The facies above this (LP2) has limited lateral extent (isolated sand bodies) and is interpreted to be deposited in lagoonal backshore environment. The facies LP3 represents tidal sand ridges parallel to paleoslope whereas the facies LP4 was deposited as prograding tide dominated delta. The reservoir characters are best developed (especially in

barrier bars and delta) in these HST sediments where the sands possess good porosity, and the geometry of deposits assures extensive lateral continuity. Throughout the Early Oligocene, the area around well A remained very shallow (2-5m paleobathymetry). While in B, for the major part of the section, the paleobathymetry fluctuated between 10-20m, while at the upper most part it is in the range of 5-10m. During Late Oligocene sedimentation began under very shallow marine condition (2-5m paleobathymetry). A gradual rise in paleobathymetry in the range of 5-10m has been recorded in all the wells of C-39 structure, towards the upper part of the succession. The area then underwent continuous base level fall which leads to deposition of FSST sediments. These sediments deposited due to forced regression during Late Oligocene are dominantly IVF, however, shoreface sands are observed towards basinal side. The reservoir characters of IVF are poor to moderate on account of amalgamated lithofacies and influence of tidal forces and burrowing activity. Incised valley fill sediments commonly occurs as pinchouts but the one that have linear sand geometry parallel to depositional slope may show fairly good connectivity. In the studied area these sands have been found to be devoid of hydrocarbons except in well J. The shoreface sands are only developed towards the basinal side and that too in the upper part of Late Oligocene (LP 7) and characterised by medium to fine grained, fairly sorted sandstone. Sand geometry of these sands generally have extension parallel to paleo shoreline. The reservoir characters are moderate to good for these sediments and can be good prospects. Upper most part of Late Oligocene sediments representing LST is widespread across the studied area. These sands are mainly IVF sands oriented parallel to depositional slope. The overlying Miocene sediments are dominantly argillaceous and show a fining up sequence indicating a transgressive regime. The dominant clay mineral in Oligocene sediments of C-39 area is kaolinite, however presence of chlorite, illite and smectite in minor to trace amount is observed. Most of these clays are authigenic and have an adverse bearing on reservoir properties. The formation of clay minerals is controlled by the provenance, depositional environment, water chemistry and diagenesis.

The study facilitates mapping of Oligocene sediments in time and space for understanding sand geometry and reservoir connectivity for exploration leads The reservoir characters are best developed in the Early Oligocene (Mahuva Formation) especially in barrier bar sands (parallel to paleo shoreline in N-S direction of the studied area) and delta deposits (parallel to depositional slope i.e N-E to S-W direction), where the sands exhibit good porosity and the geometry of deposits assures extensive lateral continuity.

Acknowledgement

The authors are grateful to Shri M. Ayyadurai, ED-BM, WOB, for providing an opportunity to carry out the work and to Dr. Alok Dave, ED-Head RGL, for constructive time to time interactions and critical review of the paper.

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