

Diagenetic Model of Bassein Formation of Mumbai Offshore Basin: A framework for future exploration in carbonates

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Summary

Journey of the Indian Plate through the warm latitudes during Middle Eocene times triggered prolific growth of platform carbonates in the Mumbai Offshore Basin. Known as the Bassein Formation, it is a Second Order Sequence, bound by Sequence Boundaries of CII-30 (Base Mid Eocene) and CII-40 (Base Early Oligocene). The profound impact of CII-40 unconformity on the Bassein carbonates is imprinted as distinctive diagenetic belts across the Mumbai Offshore Basin. Earlier work done which defined these zones of differing porosities was derived through analysis of data of over 600 wells. This paper uses the diagenetic model as a template and integrates petrophysical and geophysical methods to corroborate it. A model thus prepared, elucidates the importance of diagenetic analysis in carbonate exploration and becomes a predictive tool to focus on areas with exploration potential in Bassein Formation.

Introduction

The Bassein Formation of Middle to Late Eocene age (48.8Ma-34Ma) is an extensive carbonate platform developed in response to the deceleration of the Indian Plate, post the India-Eurasia collision. Additionally, favorable conditions of warm latitudes and reduction in sediment influx ensured prolific growth of carbonates which covered all the tectonic blocks of Mumbai Offshore Basin, excepting Mumbai High & parts of Heera Field. The Mumbai Basin comprises the tectonic blocks of Eastern Homocline, Central and Vijaydurg Graben, Heera-Panna-Bassein Platform, Mumbai High & its extended shelf as one moves westwards from the coast (Figure 1). The Bassein Formation covers each of these tectonic entities but for that of Mumbai High & Heera Fields. Over the Heera Panna Bassein Platform, the Bassein carbonates forms the primary reservoir for the producing fields of Mukta, Panna, Bassein, Vasai East, Neelam, Heera and Ratna, other than a host of smaller structures.

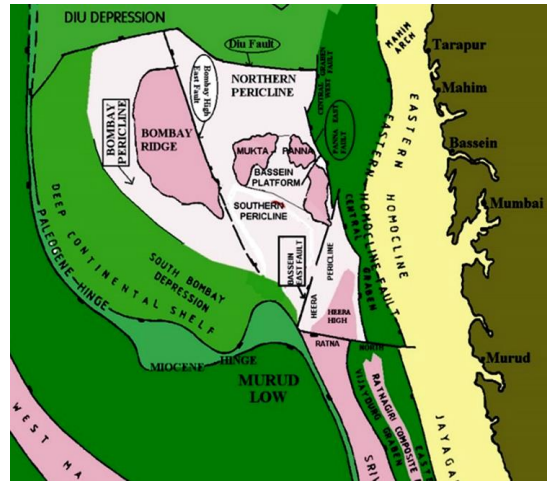


Figure 1: Tectonic Framework of the Mumbai Offshore Basin

The Bassein Formation: Depositional Environment

The Bassein Formation which is a 2nd Order sequence, is a sum of carbonates precipitated in an initial Transgressive and a later Highstand System Tract. The TST carbonates known as Lower Bassein is bounded by a regional mfs represented by a high gamma shale (Figure 2). The subsequent highstand conditions gave rise to aggradational monotonous carbonates reaching immense thicknesses.

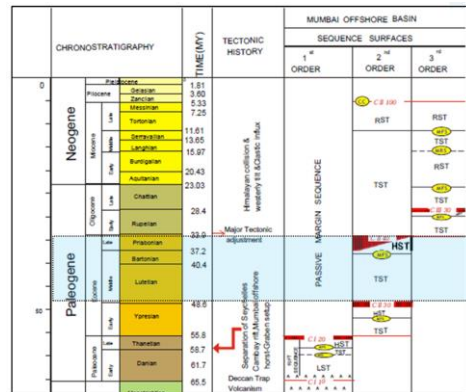


Figure 2: Sequence stratigraphic representation of Bassein Formation

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An Isopach map of the entire sequence (TST+HST) shows that thicknesses range from less than 50 m (Around Mumbai High) to a maximum of more than 700m in Vasai East. (Figure 3)

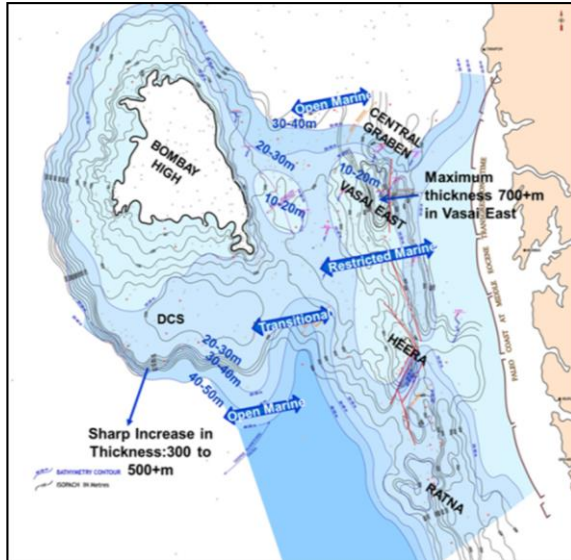


Figure 3: Isopach & Paleobathymetry of Bassein Formation (TST+HST)

Paleogeography during Middle and Late Eocene times has been interpreted based on the plethora of available data and it indicates that the carbonates have been laid down in water depths ranging from very shallow restricted marine conditions corresponding to a bathymetry of 10-20m (over Panna-Bassein-Vasai East) to transitional (>20m bathymetry, Neelam, Ratna etc.) and then open marine conditions (40-50m). The B-100/DLS area to the south, North of Mukta to the north and the western flank of Mumbai High beyond D-12 came under open marine conditions. The restricted, transitional, open marine and deeper marine conditions controlled the carbonate growth to an extent. But the thicknesses of the Bassein carbonates are entirely a factor of the accommodating faults as spectacularly demonstrated in the Central Graben/Vasai East area, where “Catch up” conditions thrived.

The Diagenetic zonation of the Bassein Formation:

The diagenetic zonation which forms the basis of this paper has been worked out earlier, through mapping of Middle Eocene unconformity, and integrating drilling and sedimentological data. The Late Eocene

time, which forms a part of the unconformity period, saw large scale withdrawal of the sea, exposing a Middle Eocene carbonate terrain. Topography of this exposure in turn was determined by the Inversion tectonics at play in the constricted parts of the Central and Vijaydurg Grabens. The resulting geomorphology consisted of raised structures (Vasai East, Bassein, Neelam) sloping west and created a hydraulic gradient for vadose zone porosity to develop.

This exposed topography is singularly the most significant factor in creation and preservation of secondary porosities within the Bassein Formation. The period of exposure and the relief of the exposed strata determined the nature and intensity of the diagenetic processes that acted on the carbonates to create what is known as the Bassein reservoir. Following a standard model of carbonate diagenesis, the five types of zones which are easily identifiable and most widespread have been mapped. (Figure 4)

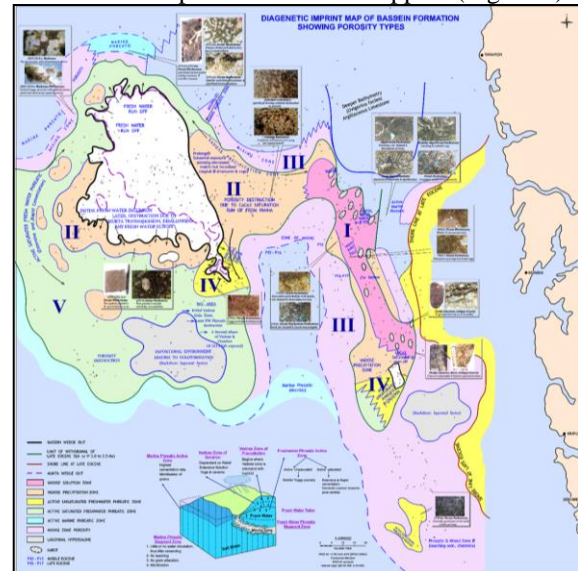
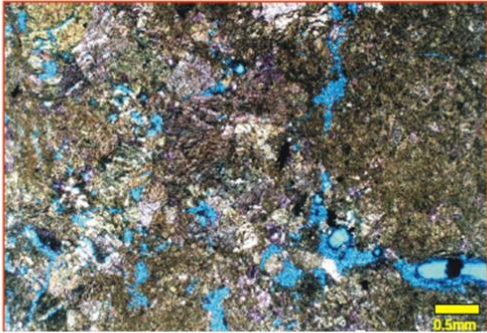


Figure 4: Diagenetic imprint map of Bassein Formation showing porosity types

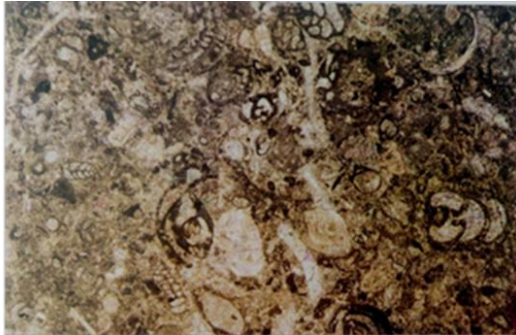
(i) *Vadose zone of solution*: The fields of Panna-Bassein, Vasai East and Neelam, which occur as a linear trend, exhibit the classical imprint of this diagenetic zone. Typically seen features are vugs, channels and intense karstification. This zone will be referred henceforth in the paper as Zone I. Westwards from this zone, the effect of intense solution activity decreases as the dissolving water progressively gets more saturated with CaCO_3 .

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Foram Wackestone- Packstone Facies depicting Solution channels and dissolution porosity as a consequence of leaching in vadose zone. (Well from Zone I)

(ii) *Vadose zone of precipitation*: Saturated runoff from the vadose zone of solution, precipitated calcite cement in adjoining areas resulting in the vadose zone of precipitation. Resultant features are equant calcite cement filling, dolomitization (where magnesium is present in the pore water). Best demonstrated by the patchy porosities of the Mukta field, lying contiguous to Zone I, referred to as Zone II in the study.



Peloidal Grainstone showing complete Sparitization (Well from Zone II)

The girdle of Zone II running parallel to the south and south-western flank of the Mumbai High wedge out, had a marginally different diagenetic history from that of the Mukta area, though the resultant porosity is similar. This area was initially under active unsaturated freshwater phreatic zone which created porosities. But with Mukta transgression taking over the area, percolating waters, laden with calcium carbonate would have precipitated and filled the pore spaces with calcite.

(iii) *Zone of Mixing*: The areas of Vadose/Freshwater Phreatic Zones grade into the Marine Phreatic Zone through an intermediate zone of Mixing. This forms the interface between fresh and saline waters where Mixing Zone porosities are created. The resulting dissolution porosities may evolve in the entire transition zone along the freshwater lens. The areas of B193/B28/ and Ratnagiri fall in the mixing zone porosity, referred to as Zone III in the paper.

(iv) *Active Unsaturated Freshwater Phreatic zone*: The fourth zone present in the study area, it occurs in the carbonates which wedge out against Mumbai High. Here, unsaturated fresh water runoff from the exposed granite inliers created porosities in the southern fringes of Mumbai High forming an area of Active Unsaturated Freshwater Phreatic zone. Referred to as Zone IV in this paper.

(v) *Active Saturated Freshwater Phreatic Zone*: Freshwater runoff through overlying/ nearby carbonate layers destroys porosities through an extensive and rapid cementation of the previously created secondary porosity. Referred to as Zone V, it covers large tracts of area in the south and west of Mumbai High where a girdle of isolated relict pockets of patchy porosities occur.

Detrending Analysis of the Diagenetic zones: The Detrending process involves removing an aspect from the data which causes some kind of distortion. So, the Detrend analysis of a data set that shows an overall increase or decrease might show the sub trends and the fluctuation which helps to further detail the analysis. As petrophysical data from wells is chaotic and fluctuating, and reflects complex natural processes it is essential to scrutinize the data by removing distortions. There are many methods for Detrending, and these techniques are often very specific to the field of study, the one which is used here for gamma ray and porosity analysis is moving the average trend lines by subtracting the mean value from each data point. The average value can be taken from the well or from the field depending on the variables in the data.

To correlate the diagenesis type and heterogeneity in porosities in the carbonates of Bassein Formation, gamma ray and PIGN logs were Detrended to analyze the sub trends. A total of 50 wells from different fields of Mumbai Offshore Basin were studied and the top 50m of the Bassein Formation

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was taken into consideration for Detrending (Figure 5).

For Detrending of porosity values, well based average values were considered but for Detrending of GR values, sector wise average values were taken. For example, the average GR value in the SW of Mumbai High area is 46 whereas it is as low as 26 in the Mukta and Heera Panna Bassein Platform. For this study, the Detrended logs have been represented along with the interpreted log of a commensurate interval to show the total effective porosity and saturation.

The Detrended data was then represented in 4 quadrants as follows:

Quadrant 1: Negative GR and positive PIGN which represents clean depositional facies where primary porosity is preserved.

Quadrant 2: Positive GR and positive PIGN which represents dirty facies with good porosity due to constructive diagenesis.

Quadrant 3: Negative GR and negative PIGN which represents clean facies with some primary porosity which may have been destroyed due to destructive diagenesis.

Quadrant 4: Positive GR and negative PIGN which represents dirty facies with low primary porosity.

Construing Q1&Q2 as high effective porosity (in green) and Q3 &Q4 as low effective porosity (in red) it transpires that all the wells which have been analyzed, adhere to the zone of diagenesis where they lie. A third category (in blue) is recognized where effect of both constructive and destructive diagenesis occur. The observations are as follows.

(i) Wells in Zone I (Karst/ solution channel prone areas) belong to Q2 indicating constructive diagenesis, wherein high porosity is observed throughout the zone.

(ii) Wells in Zone II show both porosity creation as well as destruction, (Q2, Q3) as exemplified by the wells of Mukta Field. Of the 10 wells analyzed, some show complete destruction of porosity whereas others exhibit partial development indicating uncertainty in prediction of porosity in the area. Areas close to the wedge out limit of Bassein formation, around the Mumbai High exhibits both porosity creation as well as destruction (Q2, Q3)

(iii) Wells in Zone III or Mixing zone tend to show more constructive porosities rather than destructive (Q1, Q2).

(iv) Zone IV, where Active Unsaturated Fresh water phreatic zone aided in porosity creation, wells in WO-15/16 area show porosity development irrespective of the dirty facies i.e argillaceous limestone in the top part of Bassein which indicates constructive diagenesis (Q2).

(v) Zone V or Active Saturated Freshwater Phreatic Zone, around the southern and western periphery away from the immediate wedge out areas of Mumbai High shows predominant destruction (Q3, Q4).

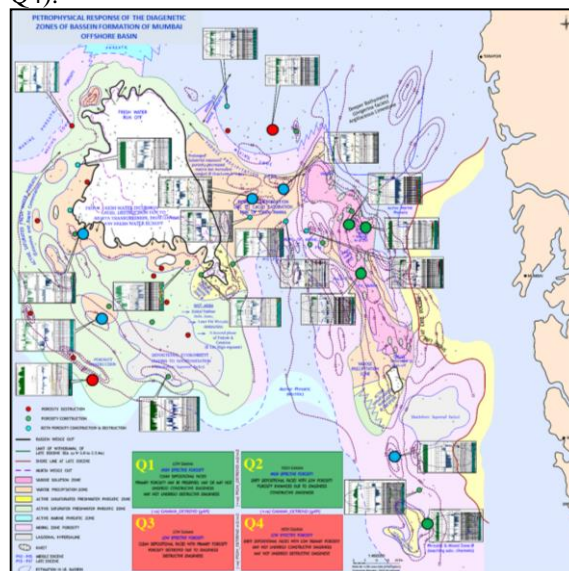


Figure 5: Petrophysical response of the diagenetic zones of Bassein Formation.

Seismic Inversion and Diagenetic zones: An attempt to demonstrate the manifestation of diagenetic zonation in seismic data was made, using Inverted seismic data over multiple 3D surveys. Attributes generated using a windowed extraction of P-Impedance for the Upper Bassein carbonates corroborate well with the derived porosity zones (Figure 6). Very low Impedance values correspond to Zone I, or areas subjected to Vadose zone exposure resulting in highest porosities, eg. Bassein, Vasai East, Neelam fields. Slightly higher Impedance values are seen to correspond to Zones II, III and IV, while the highest impedance ranges reflect areas of total porosity destruction or Zone V.

A broad relationship between porosity and Impedance in terms of numeric values is observed. Average porosity (PIGN) values for a 50m interval from Bassein Formation top was contoured and it is

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observed that an impedance range of 7500 to 8500 matches with a porosity range of 28-26% (Zone I) and 8500 to 10,500 with 26-18% (Zones III & IV). The Zone II with its complexities shows an impedance range of 10,500 to 12,000 corresponding to an average porosity of 18-12%. Values between 12,000 to 13,000 correspond to 12-8% average porosity and areas of porosity destruction show Impedance values higher than 13,000 with 6-8% average porosity.

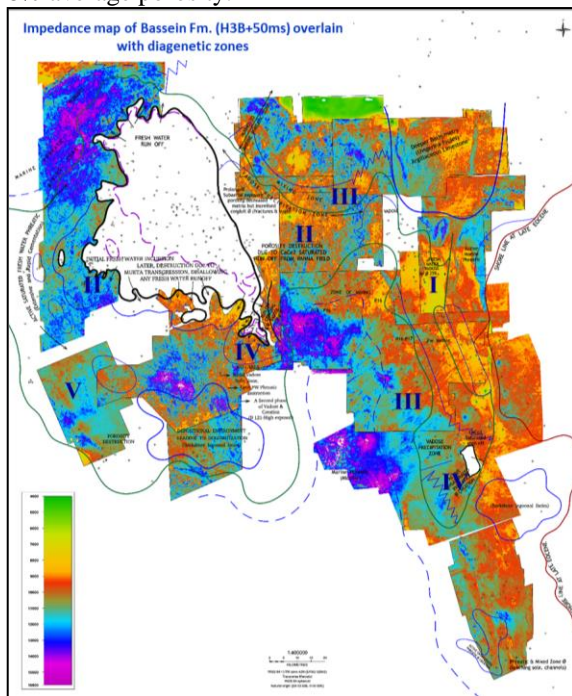


Figure 6: Impedance slice (H3B+ 50ms window) of Bassein Formation overlain with diagenetic zones

Play Dynamics of the Bassein Formation: To best evaluate the remaining potential in the Bassein Play, different aspects of the Play, like structure, reservoir quality and pool limits have been brought together (Figure 7) on a single map. A cursory examination shows that the major fields of Mumbai Offshore with Bassein as the Primary exploitable Play mostly occur along the Zone I and III trends. Till date all commercial accumulations in Bassein in this trend are exclusively structural. Zone IV, which is restricted around Heera and B-121 fields, is the other

area to hold commercial pools in structural entrapments of Bassein Formation

The accumulations in Zone II (Mukta, smaller pools in SW Mumbai High, and Well-C in B-192 area) are therefore the most intriguing since clear demarcation of porosity types cannot be done in this set-up.

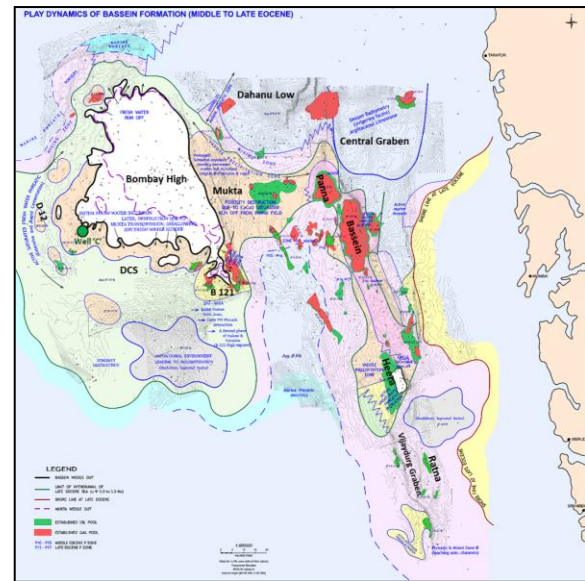


Figure 7: Play dynamics of Bassein Formation

With both constructive and destructive diagenesis at play, identifying locales with highest probability of reservoir development in Zone II depends on understanding each phase more clearly. The advantage in looking for pools in this diagenetic zone, lies in the possibility of stratigraphic entrapment as seen in Well-C of B-192 area (Figure 8). In this case, oil in Bassein Formation appears as a porosity pod, without structural advantage playing any role.

It stands to reason that future exploration potential in the Bassein Play lies in delineation of porosity pods within Zone II in stratigraphic/ strati-structural entrapment situations.

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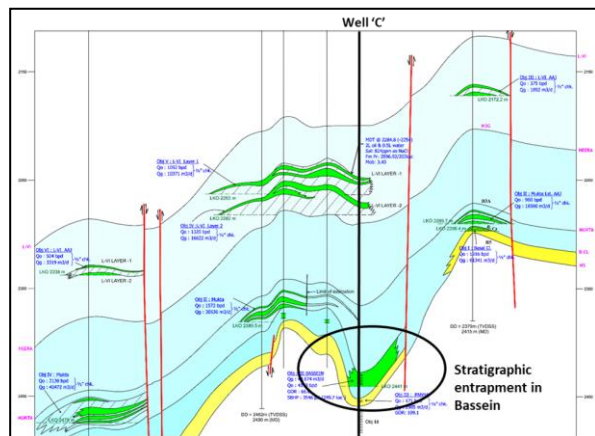


Figure 8. Geological section showing stratigraphic entrapment condition at Well C.

Conclusion

- The Bassein Formation which is a Second Order Passive Margin sequence, had its reservoir properties bequeathed to it by the Sequence boundary CII40.
- The complex relationship between the diachronous nature of the Middle-Late Eocene unconformity, tectonic upheavals during the period and their combined influence on the kind of porosity generated/ destroyed resulted in well-defined zones of porosities.
- Five most prevalent Diagenetic zones which were mapped earlier have been corroborated through Detrending of petrophysical data from 50 wells. Constructive and Destructive diagenetic trends deduced from GR and PIGN data, fitted the identified zones.
- Similarly, Impedance studies across multiple 3D volumes substantiate the presence of distinct girdles of porosity.
- Since the heydays of big discoveries in structural entrapments with ideal reservoirs is long gone, teasing out the more subtle traps within this Play is the present challenge. The Zone II of porosity creation as well as destruction in possibly multiple cycles, holds the most promise in this regard.

References

- Bagchi N., Mathur G. (2018), Diagenetic Imprint of the Base Early Oligocene Unconformity on the Middle-Late Eocene carbonates, APG
- Dave A. (1999), Paleokarst process response model of Bassein Formation B-Zone upper, Neelam field. Integrated lab studies; RGL
- Mazzullo S.J. (2004), Overview of porosity evolution in carbonate reservoirs;
- ONGC internal Reports
- PS CUBE report ONGC
- Singh Dhruvendra, Upadhyay H., Choudhary P.K., Khan D.A., Vushim A.T. (2004), Microfacies analysis, diagenetic history, reservoir characterization and relationship with fluid transmissibility of Bassein Formation, Bassein and adjoining areas; RGL
- Vasudevan.K, Singh D, Singh S.K, Kapil A, Singh U, Ghosh A, V Kumar (2017) Reservoir characterization of Panna and Bassein Pays of Vasai Field, GEOPIC

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