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Diagenetic Imprint of the Base Early Oligocene Unconformity on the Middle-Late Eocene Bassein carbonates

Abstract

Over the Mumbai offshore, the end of Early Eocene is marked by an unconformity period of >2Million years and forms the first 2nd Order Sequence boundary, CII-30. The overlying 2nd O Passive Margin sequence covers the Middle-Late Eocene Chronospan and is bounded by the 2nd O sequence boundaries of CII 40 (Base Early Oligocene) and CII 30 (Base Mid Eocene) (*PS Cube report,Dave et al,unpublished report*). The sequence is identified as the Bassein formation and is mainly represented by widespread platform carbonates. It forms one of the major reservoirs in the area and is host to the giant gas field of Bassein and a number of smaller hydrocarbon bearing structures. The significance of Bassein Formation as the primary reservoir of the platformal area cannot be overstated. To this end, it was felt that a fresh look at all the accumulated data might yield new insights. Moreover, the abundance of structural entrapments in the area has effectively kept the focus of exploration on the upper layers of the Bassein Formation, as a result of which, the Middle and Late Eocene carbonates came to be treated as one entity. To address this lack of differentiation in our understanding of the carbonates of Bassein Formation, an exhaustive collation of available palaeontology and sedimentology data, coupled with drilling information was done. The paper is the culmination of the study which analysed diagenetic data, porosity distribution, drilling complications and lab reports from over 600 wells which helped to model the porosity zones over the Mumbai Offshore block. This study is an attempt to give a holistic view of the Bassein carbonate porosity generation and distribution across the Mumbai Offshore. It is a first ever attempt in classifying the porosities on the basis of diagenetic zones and preparing a predictive model for a better regional understanding of the area.

Introduction

The Bassein Formation was deposited in response to the slowing down of the Indian Plate post India-Eurasia collision. It covers almost all the tectonic blocks of Mumbai offshore block, except the Bombay high. The marine transgression post CII30 began with the precipitation of TST carbonates classified as Lower Bassein. A high gamma shale marker marks the regional mfs at the end of the TST. This was followed by the

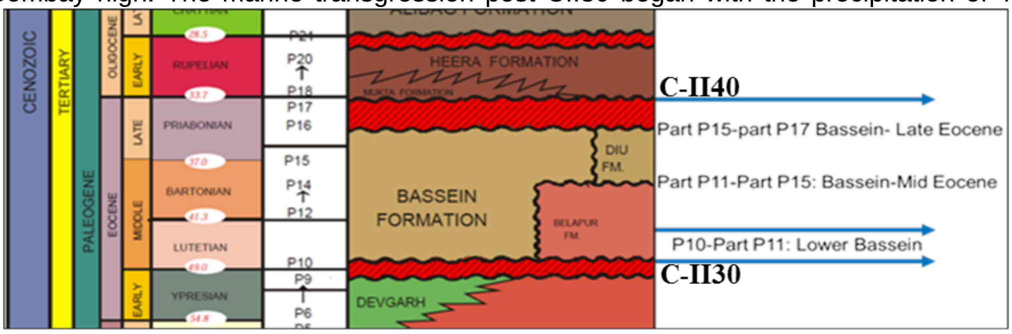


Fig 1: Stratigraphic Chart showing identified P-zones

preceipitation of the aggradational HST carbonates which are terminated by the Base Early Oligocene unconformity CII40. CII 40 can be related to the major drop in sea level after HOM I (Development of Murree Foredeep, ending 41.3Ma). Chronostratigraphically the Bassein carbonates can be divided into, Middle Eocene, including the TST and lower part of the HST, and Late Eocene, the upper part of the HST. The P Zones defined on the basis of relative abundances of stratigraphically important planktonic foraminiferal species have been used to identify the chronostratigraphic boundaries **(Fig 1).** The Bassein Formation has thus been divided into Middle and Late Eocene based on P-zones P-10 to part P-15 of Middle Eocene age and part P-15 to P-17 of Late Eocene age. The unconformity period which is diachronous in nature over the Mumbai Offshore, is best established by the distribution of Late Eocene carbonates. The Nummulites fabianii- Pellatispira sp- N.pengaronensis biofacies is the characteristic assemblage for this period. The planktonic foraminiferal zones which determine the boundaries are that of part P15, P-16 and part P-17 ranging in age from 37 to 33.7Ma. Since the Bassein unconformity period extends from Bartonian (~37Ma) to end Priabonian (33.7Ma), The absence of Late Eocene points towards a longer period of erosion or non-deposition, while a continuous Middle-Late Eocene sequence indicates a shorter period of exposure. The porosities developed within the Bassein carbonates are seen to be highly dependent on the period of exposure as well as the relief of the exposed strata.

The thickness distribution of the Bassein Fm'n strata over the area throws up interesting observations. On comparision, the thickness contour in the area around Central High is similar to to that of the Heera high (around 170m). However, age data over Heera field unequivocally places the unconformity period at>3.5Ma within the 250/200m contour, while the Central high shopws an unconformity period of 1.5Ma. Both these areas are known to be paleohighs, as evidenced by the distribution of deeper formations, so it follows that in the absence of any modifying tectonics during Middle-Late Eocene, a similar pattern would follow during the precipitation of the Bassein carbonates. If the aforementioned premise were true, then the Central High should also have had an unconformity period of the same order. But age data, shows continuous presence of Middle to Late Eocene fauna (planktonic zones P-13 to P-16).Similar mismatch was seen over the Bassein and Vasai East areas where where the presence of more than 200m of Late Eocene thickness is juxtaposed against Mid Eocene strata within the low in a mere 2km distance. This did not have any tenable explanation. No amount of "accommodation creation" or "catch up conditions" could explain the 200m missing Late Eocene deposits in a 2000m distance where the higher thicknesses showed an unconformity period of 3.5Ma while the paleohighs showed continuous deposition **(Fig 2a, 2b)**

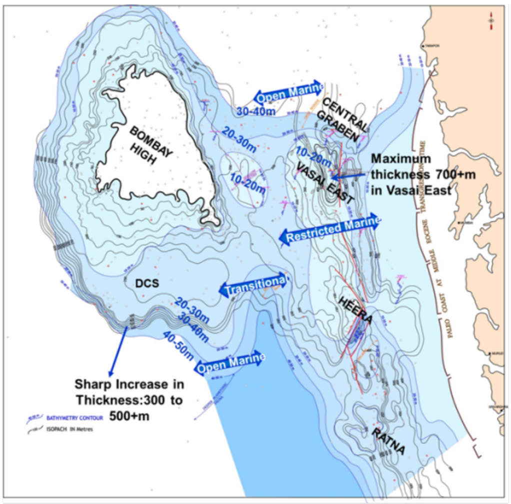


Fig 2a: Isopach,Paleobathymetry Bassein Lst at Middle Eoc. (TST+ HST)

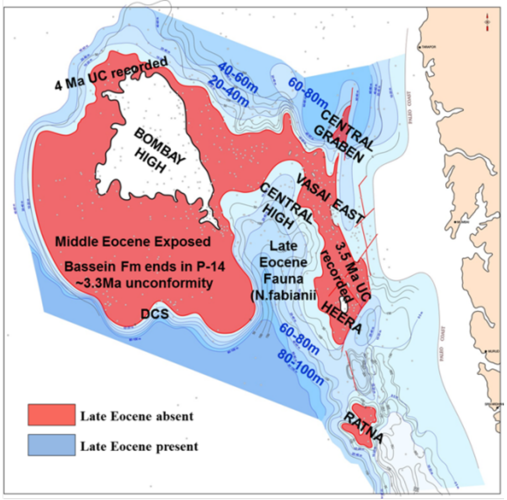


Fig 2b: Isopach, Paleobathymetry of Bassein Lst at Late Eocene

These observations led to the conclusion that the faults in these areas had started to reverse their movement during Middle Eocene time creating a connected, raised topography with the known paleohighs of Panna-Mukta, B-179 and Heera. The Inverting faults then would raise and expose the blocks of Neelam, Vasai East-Bassein to create a topography which was far more pronounced than that of the surrounding exposed terrain. The other evidence is the development of karst zones, which depend on the position of the water table in relation to the exposed topography, which in turn determines the vadose and phreatic zones. Therefore the two hundred metre karstified limestone of Vasai East, Bassein and Neelam Fields, could only have been created due to vadose zone exposure of more than 200m. The Isopach map of Bassein Formation in the Vasai East suggests that during the deposition of Bassein Limestone, the Panna-Bassein main fault and the fault bounding the eastern edge of

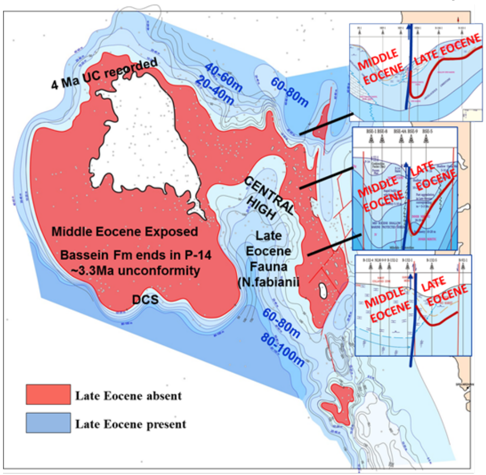


Fig 3a: Isopach of Bassein Lst at Late Eocene with schematic sections depicting the inversion topography

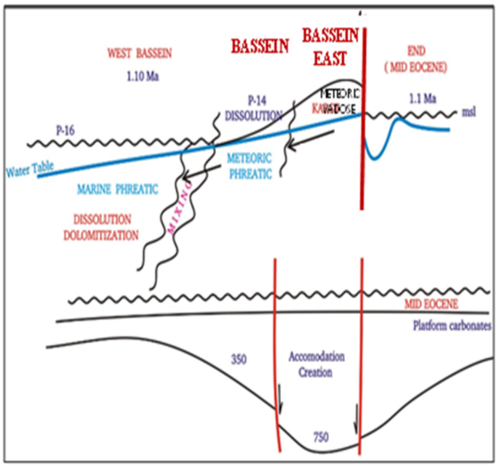


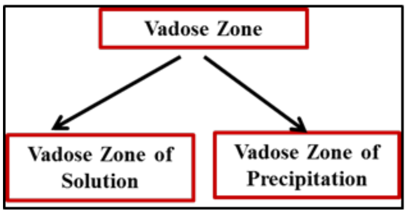
Fig 3b: Schematic diagram depicting the diagenetic zones relative to the water table

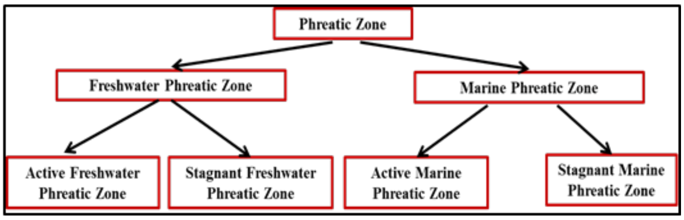
the Vasai East Field, created

major accommodation due to which the limestone growth kept pace in a “catch-up” situation, accumulating more than 700m of Middle Eocene carbonates. The Immense thickness at some point of time, (probably end of Middle Eocene) caused these extensional faults to change their movement to compressional and create inverted structures along these faults. The positive topography generated due to the structural inversion along these faults would slope gently to the west and have a steep rise to the east, making the eastern flank most receptive to vadose zone dissolution. Water movement in the vadose zone which is gravity driven would then be directed to the marine phreatic realm to the west.Inversion tectonics at Middle Eocene once envisaged, helped to unravel a lot of unanswered questions. Primary amongst them being the distribution of Late Eocene.

Diagenetic imprint of the Base Oligocene Unconformity (CII-40)

There are three major stages of diagenesis. The primary porosity, created during the pre-depositional and the post depositional stage secondary porosity. The major diagenetic processes like cementation, dissolution, and dolomitization, all require significant flow of groundwater, driven by an externally imposed hydraulic gradient. It occurs in a consistent sequence of four diagenetic zones: The Vadose Zone, Freshwater Phreatic, Marine Phreatic and an intermediate Mixing Zone (*Hartmann D.J, Edward A. 1999*). This is the classification that has been followed in the present study to bring out and explain the porosities in the Middle Eocene carbonates





The Vadose Zone is the zone between the surface and the water table. It is a two phase system in which both air and water operate controlling the creation or destruction of porosity. The Vadose zone is further subdivided into Vadose Zone of Solution and Vadose Zone of Precipitation. Vadose Zone of Solution is where the dissolution of carbonate sediment occurs as a result of meteoric water movement. As the initially undersaturated fresh water percolates downwards or moves across carbonate terrain laterally, carbonate is dissolved the water increasingly becomes saturated with $CaCO_3$. As the water crosses its saturation point, the precipitation of calcite takes place through evaporation or release of CO_2. This is the Vadose Zone of Precipitation. Below the water table is the phreatic zone which is characterized by a almost 100% saturation of water, which gives it a very high diagenetic efficiency due to the presence of large volume of water

Active Freshwater Phreatic Zone (AFPZ) is the zone where freshwater movement takes place below the water table. The carbonates may be dissolved, creating porosity, or may be precipitated, destroying porosity, depending on the $CaCO_3$ saturation of the water which in turn depends on the terrain through which the meteoric water percolates down to reach the phreatic zone. The Stagnant Freshwater Phreatic Zone (SFPZ) is the zone of equilibrium between the surrounding rock and the pore water. This zone is characterized by little or no movement of water and as a result the porosity previously created in the overlying zones are generally preserved.The Marine Phreatic Zone is completely marine and is usually the zone where carbonate sediments are originally precipitated. This zone is $CaCO_3$ oversaturated and hence is mainly associated with the destruction of porosities and Dolomitization. The maximum destruction of porosities occurs in the Active Marine Phreatic Zone (AMPZ). This is the zone of waves, tides and currents that force water through pores leading to cementation and micritization of grains. Mg calcite or aragonites are the cements that precipitate in the AMPZ. As the saturated marine water percolates deeper it enters the Stagnant Marine Phreatic Zone (SMPZ) where very little or no movement of water takes place. This zone is below the influence of waves and tidal currents and very little minor intragranular cementation or very little micritization happens in this zone as a result of which the porosities are preserved.

The Middle-Late Eocene carbonates are prolific producers of hydrocarbon in some areas white porosities ranging from 25-30%, while in other areas the porosity drops to below 8%.As the porosity data was plotted on a map, distinct zones came up. The zone of Karstification was characterized by very high porosities, blind drilling due to uncontrollable losses, large scale cavings and collapse features. The karst features are characteristic of the Vadose Zone of Solution. This is where the unsaturated fresh water runoff over the exposed topography dissolved the carbonates giving rise to secondary porosities in the form of vugs, channels and intense karstification.

A schematic topography section drawn across the Panna Mukta field, the Bassein field and the Vasai East field shows brings out the model in its entirety **(Fig 4).** The inversion fault system active during Late Eocene raised the topography around the Bassein field and the BSE-7 area to as much as 200m above the sea level, exposing Middle Eocene and leaving it susceptible to Vadose zone diagenesis.

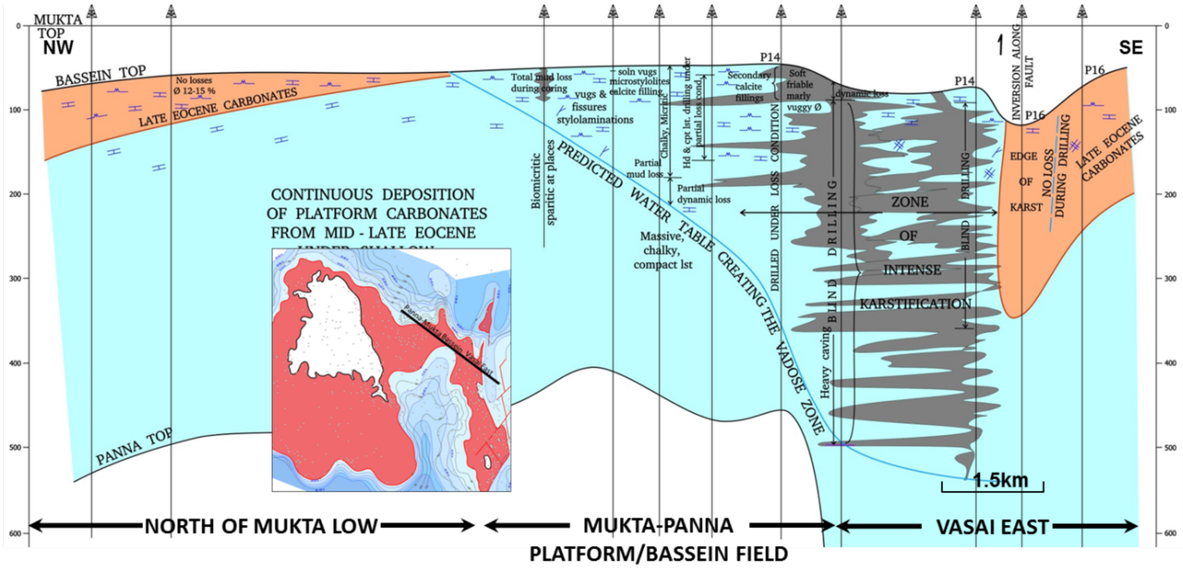


Fig 4: Section across Mukta-Panna platform-Bassein field and vasai east areas depicting the karstified Middle Eocene carbonate juxtaposed against non-karstified Late Eocene

On moving away from the exposed topography and closer to the phreatic zone, the evidence of intense solution activity decreases. The large karstified terrain changes gradually to solution vugs, channels and chalky limestone with a proportionate decrease in porosity.

Taking the above conclusions forward, a predictive model was made for the entire Mumbai offshore delineating the diagenetic zones **(Fig 5)**. The control of the topography post Late-Eocene inversion is clearly bought out. The oversaturated water, as it runs off from the high relief exposed terrain of the Vasai East and Bassein Field and onto the flat topography of the Panna-Mukta fields loses its capability to dissolve more $CaCO_3$ and this is when it starts precipitating. The water enters the Vadose Zone of Precipitation where even a slight temperature increase or CO_2 degassing results in the precipitation of calcite. This is seen in the patchy porosity of the Mukta Panna fields. There is dolomitization, and equant calcite cement filling the vugs, resulting into overall loss of porosity. However even though the area was exposed and had a low relief, it still remained in the Vadose Zone due to which the porosity was not destroyed completely.

Between the Vadose Zones and the marine phreatic Zones lies an intermediate zone of Mixing. This forms the interface between fresh and saline water. The Mixing Zone porosities are erratic depending on the relative saturation of the percolating water. The mixing between seawater and freshwater creates a sharp transition zone. Mixing of relatively undersaturated groundwater, and supersaturated sea water with respect to calcite causes undersaturation of the mixed solution. The resulting dissolution porosities may evolve in the entire transition zone along the freshwater lens. The areas of X193/X28/ and Ratnagiri show a patch mixing zone porosity.
The deeper areas of X28/X193 in the south and North of Panna-Mukta platform were under continuous deposition from Middle through Late Eocene underwent a very short hiatus of about 1.5Ma. These areas were dominantly under the Marine Phreatic zone for the larger part of the unconformity period. The Phreatic zone is 100% saturated with water and is further subdivided into AFPZ and SFPZ. The AFPZ is the zone of active precipitation or destruction of porosity. The saturated meteoric water that passed from the Vadose zone now enters the Marine Phreatic realm

through the intermediate Zone of Mixing. In the DCS area the carbonate terrain gives way to mammoth exposed granitic inliers of Mumbai high, where water runoff from the exposed granite inliers is unsaturated since it had no carbonates to dissolve. This forms an area of Active Unsaturated Freshwater Phreatic zone. However the subsequent Early Oligocene transgression was responsible of an almost total destruction of porosities. As the Oligocene transgression progressed, it covered the almost uniform flat peneplained surface of Middle Eocene with a shallow water depth of 5-20m. A thin layer of Oligocene carbonates covered most of the area and the fresh water runoff from the Mumbai High granitic terrain now had to pass over this carbonate terrain dissolving and creating fresh secondary porosity in Early Oligocene limestone. This resulted in the Middle Eocene carbonates being pushed into the Active Saturated Freshwater Phreatic Zone. The water dissolving the thin carbonates of the overlying Oligocene became saturated and percolated down into the Middle Eocene deposits. This led to an extensive and rapid cementation of the previously created secondary porosity. The limestones were micritized and dolomitized, the vugs were filled and the pore spaces were

break in the XD-1 area there is a continuous deposition in the Marine Phreatic realm with very little creation of secondary porosity.

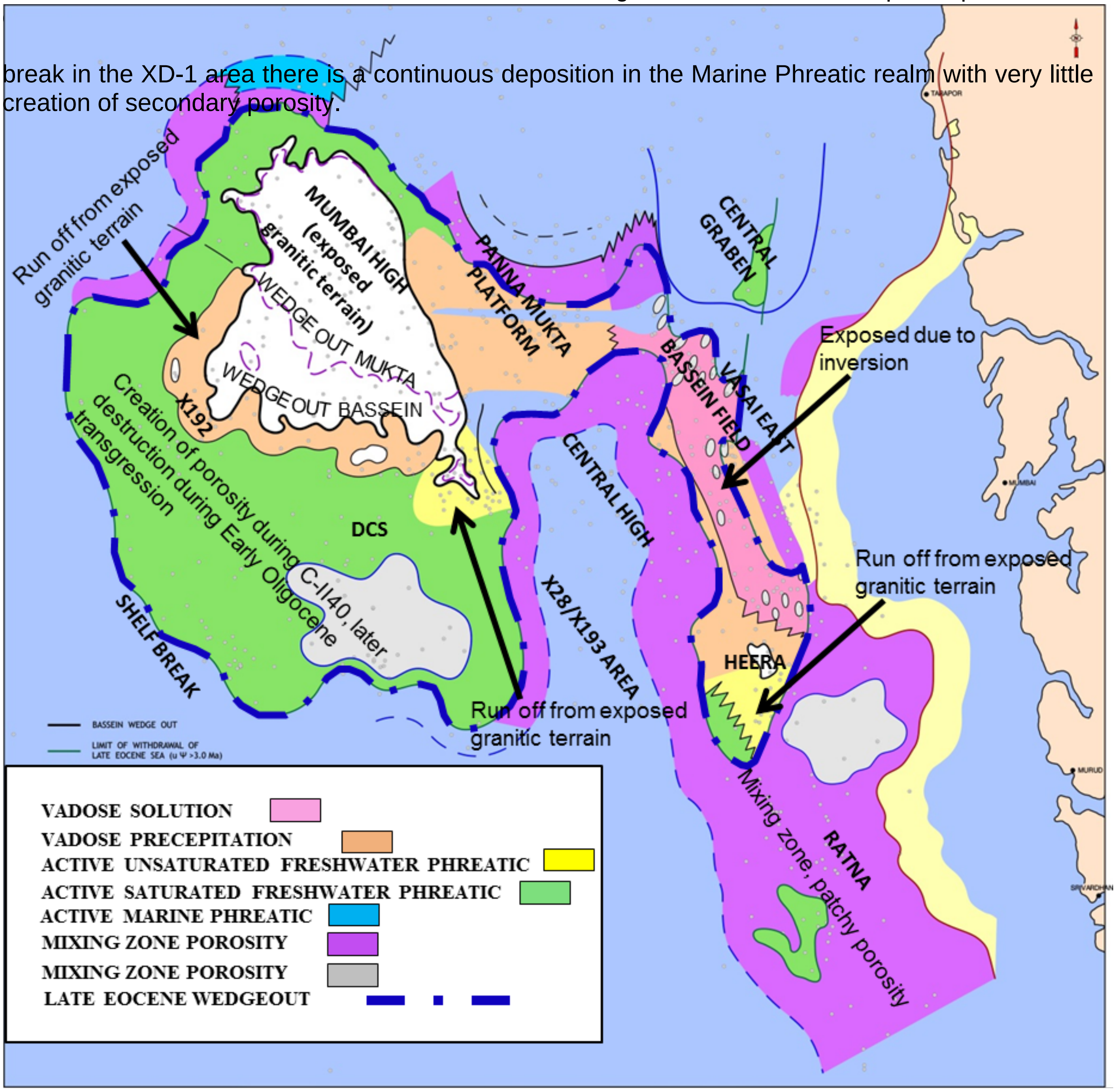


Fig 5: Diagenetic zones over Mumbai Offshore

Conclusion

The understanding and insight gleaned from analysis of data from over 600 wells has helped to identify the nuances in behaviour of the Bassein limestone. The behavioural difference is linked to the age of the limestone and period of unconformity it is subjected to. This in turn is controlled by the tectonics of Inversion during the Middle Eocene. The landform thus created, exerted a direct influence on the kind of porosity generated. Spatial representation of these porosity belts can be used to predict drilling behaviour, porosity type, salinities, diagenetic effects etcetera. Late Eocene time saw large scale withdrawal of the sea exposing the carbonate terrain. The extent of the unconformity has been mapped for the first time. The exposed topography is the singularly most significant factor in creation and preservation of secondary porosities within the Bassein Formation. The geomorphology during the Late Eocene unconformity is linked to the Inversion faults which raised structures and created a hydraulic gradient for vadose zone porosity to develop. The inextricable link between topography, period of exposure and creation/ destruction of porosity has been established through mapping of the various kinds of porosity through this study.

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