PaperID **AU340**

Author **DEEPIKA SINGH , ONGC , India**

Co-Authors **Harjinder Singh, Anil Thapliyal, Suparna Chowdhary, Ankur Mundhra**

Imprints of Depositional Environments on Diagenetic Changes and Production Behaviors of Heera Field, Mumbai Offshore Basin

Abstract

Discovery of yet to find oil in mature basins and in and around well explored fields requires new inputs, either in material (new and advanced data) and/or new ideas. The present study pertains to Heera Field of Mumbai Offshore Basin. Though exploration/ production in and around the study area have been going on for almost last four decades from the Middle Eocene- Oligocene Limestone of Bassein / Mukta Formation, the least attention has been given to Panna Formation (Clastic) and Heera Alternation (Tight Reservoir). Objective of current study is to develop a comprehensive model for exploration and further delineation of different reservoirs (From Panna, Bassein and Mukta to Heera Alternations) and to understand the porosity development and reservoir characterization in Heera field.

After integrating heterogeneity from micro to mega scale, a static model was developed to understand porosity distribution and its continuity. The inferred depositional model of shoal zone and vadose zone diagenesis along the exposed geomorphic highs indicated towards the cyclic creation and destruction of porosity during deposition of multiple phases of Bassein carbonates.

The Proper mapping of the Basement and Panna Formation tops and net sand thickness from well data gave the realistic assessment of exploitable hydrocarbons of Panna Formation. The inferred dispersal geometry of Panna Formation in good agreement with the drilled well information and aid in the identification of additional areas for exploration, delineation and development for placement of infill wells in North Heera. Mapping of Heera Formation has also helped in estimation of its areal distribution, thickness variation and developmental potential in the field.

Introduction

The field is known to produce hydrocarbon from carbonates formed during middle Eocene transgression Bassein Formation, followed by the unconformity at the top. The study area is a unique example of a complete cycle of Transgressive- Regressive (T-R) cyclic deposition where different type of reservoir (from Clastic to Carbonate) deposited during the different phases of transgression and regression on the floor of Archaean Basement. The present case study is an attempt to integrate the distribution of diagenetic alterations into the sequence stratigraphic framework of isolated marine carbonate platform and its depositional successions.

Geological Setting

The tectonic block (Fig.1) is dominated by extensional tectonics and all major faults are parallel to NNW-SSE (Dharwarian) and ENE-WSW (Satpura) trends. Heera Field is a fault closure bounded by NW-SE fault in the east.

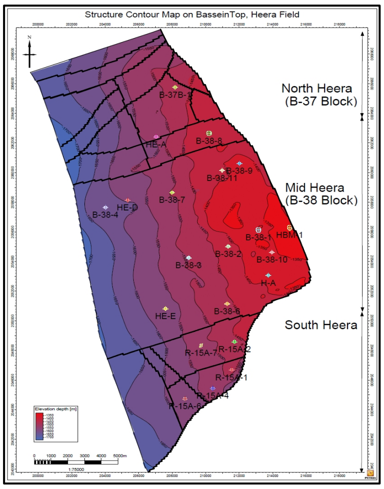

Fig-1. Heera Field

Fig.2 Stratigraphy of Heera Field

Two East-West trending faults further subdivide the Heera Field in northern part. The ENE-WSW trending sealing fault separates Heera and South Heera fields. Two structures which constitute Heera Field are B-38 and B-37B-1 separated by graben (B-38-8 well area). R-15A-1 structure falls in South Heera Field. The general dip (2-3°) of the Field is towards west (Fig.2).

Sequence Stratigraphic Correlations

Well data was loaded after quality check using Petrel software in the WGS-84 coordinate system. The stratigraphic markers H5 (Basement), H4 (Panna), H3B (Bassein), H3A (Mukta), H3G (Heera Alternations) from bottom to top were identified on the basis of log response and correlated across the area for understanding lateral Facies/lithological variation (Fig-2). The electro log correlations were carried out using Sequence Stratigraphic Correlation approach across the area. West-East Sequence Stratigraphic correlation (Fig.3) indicates the Basement shallows towards the East and the Pays of Bassein and Panna gradually pinch out against the Basement.

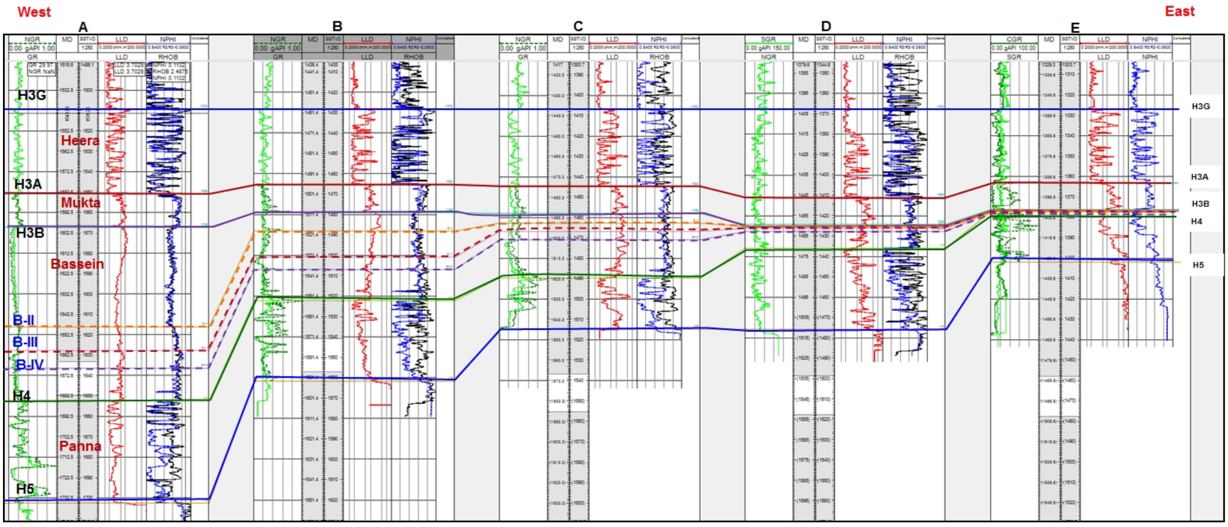

Fig-3. West- East cross section showing Sequence Stratigraphical correlation in Heera field

Depositional Environment

The Heera Platform witnessed its first regression in the form of Panna Formation where major clastic depocentres were on the western flank and Archaean basement was exposed at the crestal part of Heera structure (Fig.4). The Panna formation unconformably overlies Basement (H5) and the top of Panna is erosional unconformity (H4). Lower part consists of medium to coarse grained, moderately consolidated sand stone along with shale. The coarser grained clastics of continental, possibly fluvio-deltaic type distribution patterns suggest erosion of exposed Archaean basement.

The first marine transgression with cyclic eustatic sea level changes led to prolonged marine flooding during the Middle Eocene, when extensive platform limestone of the Bassein Formation were deposited. Transgressions occurred rapidly because the surface of the platform was wide, flat, and had a very gentle dip (2-3°). A relative sea level rise of only a few meters inundated large areas of the platform. The Bassein Formation unconformably overlies Panna Formation (H4) and is absent on the crest of the Heera field but thickens down dip towards the west, as a combined result of depositional slope and subsequent erosion. Due to cyclic seal level changes, multiple phases of Bassein carbonates deposited from Lutetian to Priabonian spanning 14MYears in form of B-I, B-II, B-III and B-IV. Bassein Formation is dominantly represented by carbonate facies, with a few shale intercalations. Microfacies in the area are represented by Foram Algal Wackstone/Packstone in the upper part to low energy mudstone/wackestone (Fine Foram Debris) in lower part (Fig. 5) with a shale layer at the top, suggesting an oscillating sea level. Sedimentation was closely balanced by uplift and subsidence, which resulted in alternating episodes of sedimentation and erosion.

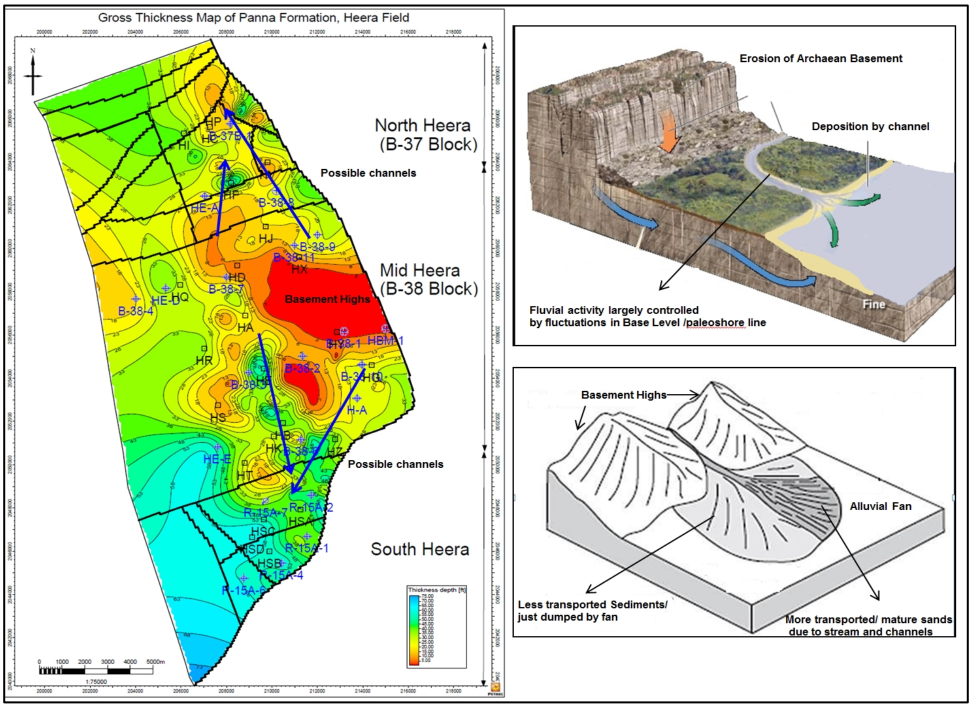

Fig-4. Gross Thickness map of Panna Formation and its Depositional environment

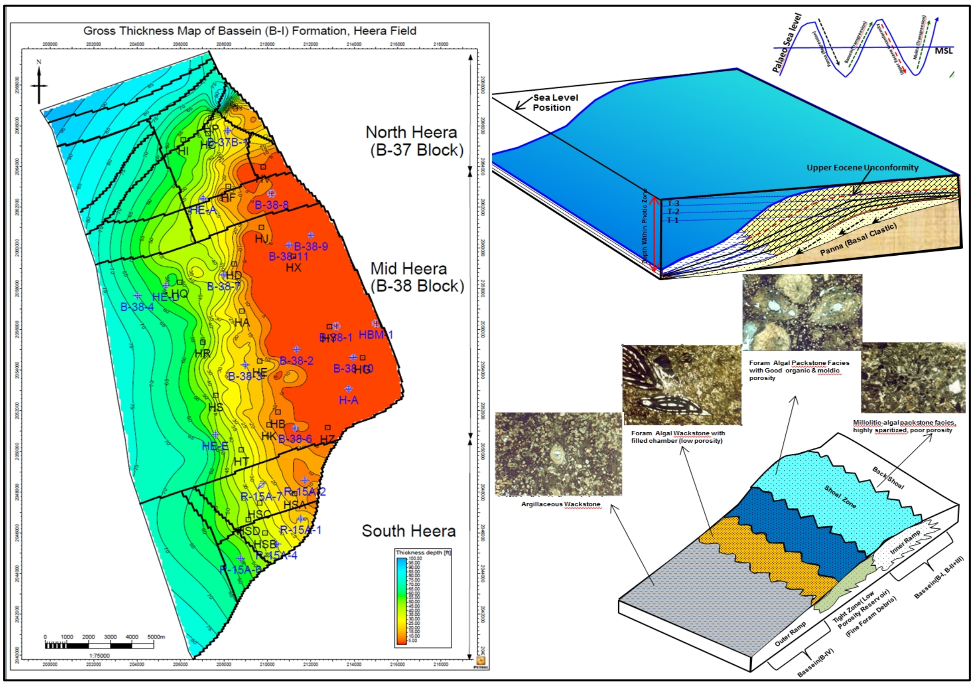

Fig-5. Gross Thickness map of Bassein (B-I) Formation and its Depositional Environment

After Bassein deposition, the area again witnessed a regression in upper Eocene and a period of non-deposition / erosion spanning 3.3MY. The Mukta and Heera formations Formation (combined thickness of up to 65 m; Mukta of ~15-25 m & Heera ~40-50 m), is marked the Transgressive event in lower Oligocene and is characterized by lagoonal carbonates, mudstones with paralic shallow-marine shale intercalations. Mukta Formation overlies the Late Eocene unconformity and is thick across the entire field & developed better in South Heera. Heera Formations forms the cap rock for Mukta and Bassein formations. Some limestone layers are porous and hydrocarbon bearing but lateral correlation is difficult. These layers are developed in patches and better developed in South Heera.

Porosity Distribution

The Deposition of Panna Sands is mainly controlled by underlying Basement architecture, paleorelief, and fluvial drainage pattern. Panna Formation is hydrocarbon bearing in the Basement lows, whereas absent in Basement high. The development of porosity in Panna Formation is primarily developed due to alteration of rock fragments into their constituent minerals and textural maturity gained due to longer transportation. The best reservoirs Facies are encountered in the southern part and crestal part of field, where good intergranular porosity with micro fractures are present. In North Heera field the texturally immature sediments/sand deposited in the intervening lows with short distance transportation, where porosity is observed in the form of Micro-fractures, micro-vugs and Intergranular pores (Fig. 6).

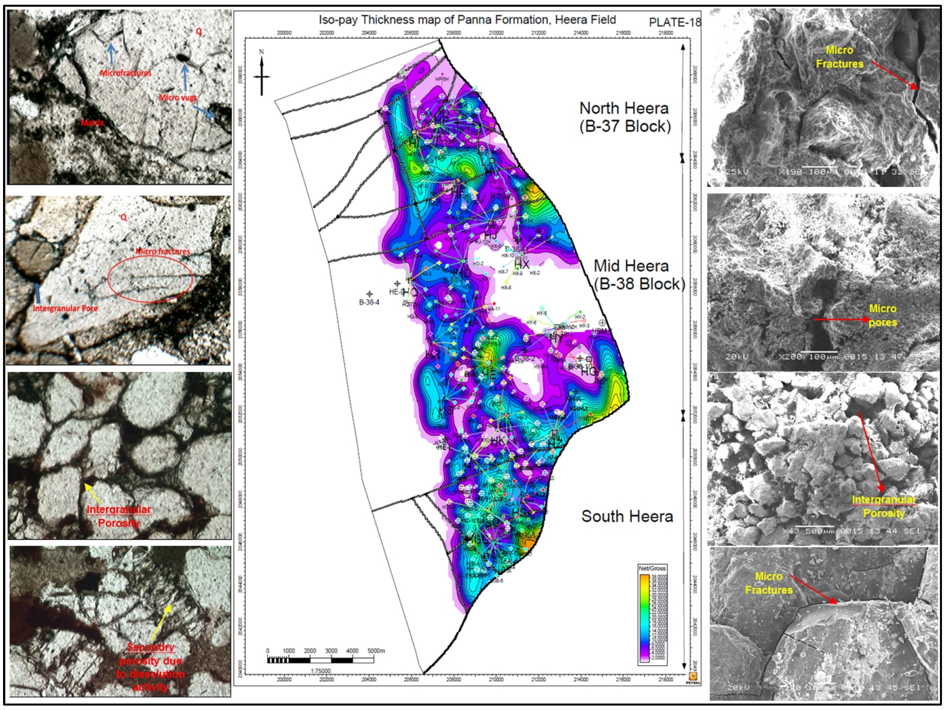

Fig-6. Effective Thickness map of Panna Formationand its Porosity Distribution

The Bassein formations' (B-I, B-II, B-III Zones) are predominantly of Shoal Zone/Inner Ramp Environment and these facies are mostly having good organic and mouldic porosity, Whereas B-IV Zone is (Fine Foram Debris) of Outer Ramp Environment with partly filled chambers of forams and micritic porosity. Clay contains kaolinite, montmorillonite and traces of illite.

Porosity development in Bassein Formation is moderate to good in the top most part, which occurs as large solution vugs and channels. The primary porosity is intergranular and in the empty chambers of forams, it is effective only when enhanced by solution activity. Secondary porosity occurred mainly because of karstification in the form of vugs, solution channels, moulds (coral and shells) and fractures and played a key role in the enhancement of the reservoir quality in compare to primary porosity. Dolomitic Porosity (Intracrystalline porosity) and pressure solution porosity is also very common in Bassein formation at some places. The secondary porosity is best developed in B-I and B-II zone, but decreases with depth. Cyclicity in the porosity creation and destruction is observed throughout the stratigraphic succession, which is governed by lower order, high frequency sea level oscillations and the consequential hiatuses leading to exposure of geomorphic highs (Fig. 7).

The porosity distribution in Mukta and Heera Formation reveals tight and compact limestone with moderate to poor porosity and permeability. Primary porosity is in form of intercrystalline, intraparticle and Organic porosity within Foram Chamber. The primary porosity is destroyed due to pyrite filling, sparry calcite and secondary calcite precipitation during diagenesis. Secondary Porosity in the form of numerous Vugs and Micro-vugs due to solution activity is also very common. (Fig.8).

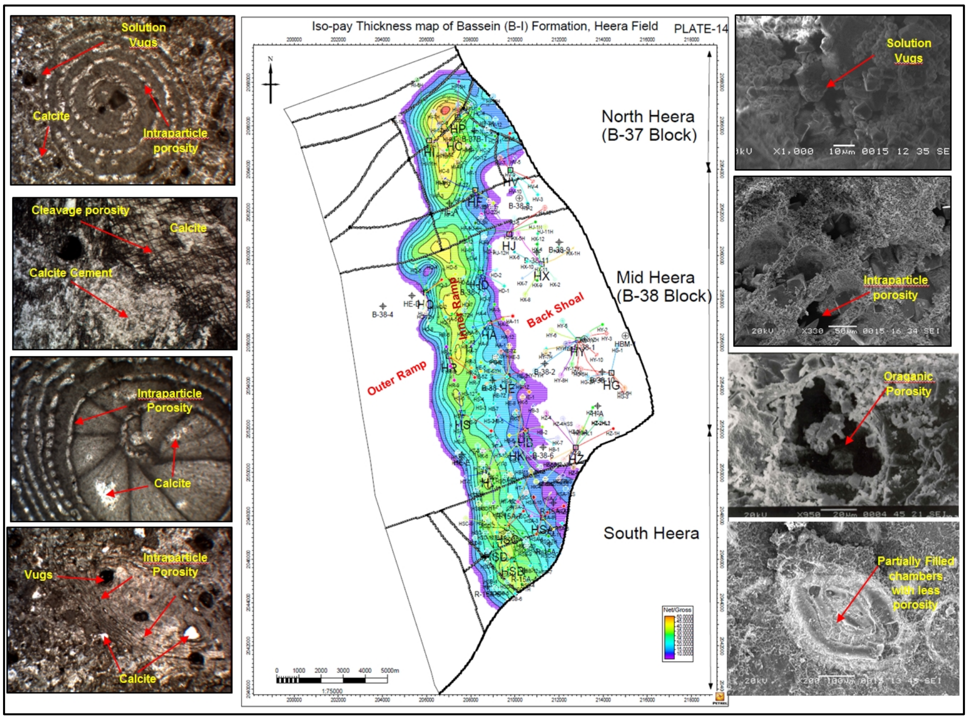

Fig-7. Effective Thickness map of Bassein (B-I) Formation and its Porosity Distribution

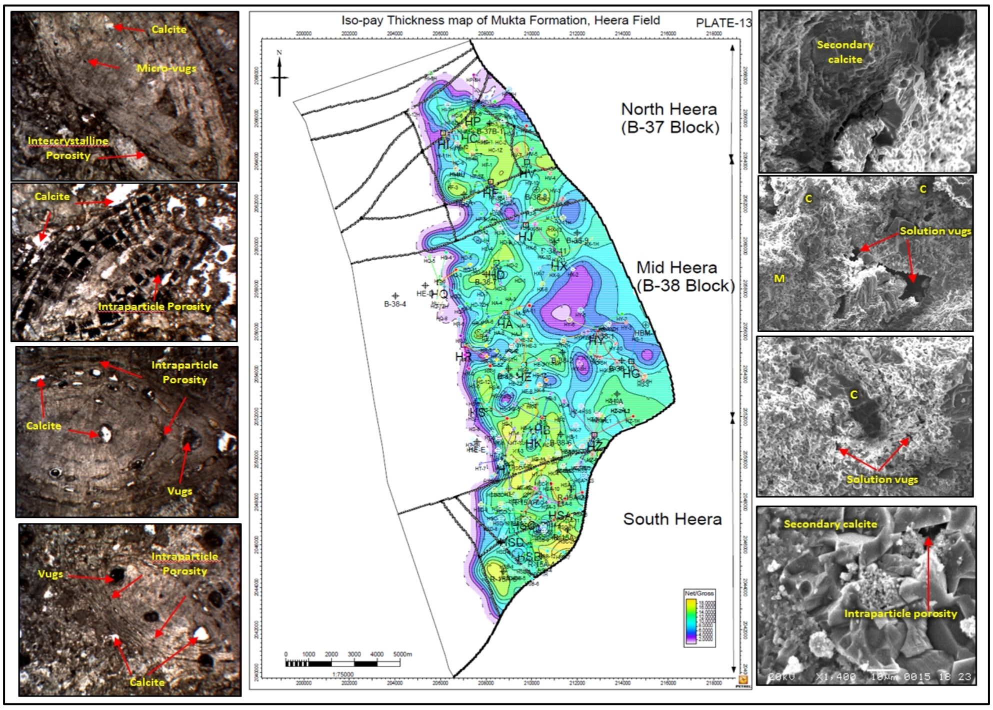

Fig-8. Effective Thickness map of Mukta Formation and its Porosity Distribution

Petro physical Modeling

Porosity Model was generated by Gaussian Random Function Simulation (GRFS) where well based porosity was used as primary constraint which was co krigged with average porosity of each zone as the secondary variables. Saturation Model was generated by Trend Modeling where zone specific processed logs were used during the upscaling is given as primary constraints. Different trends in the form of up scaled effective porosity and average water saturation were given as secondary constraints. (Fig.9).

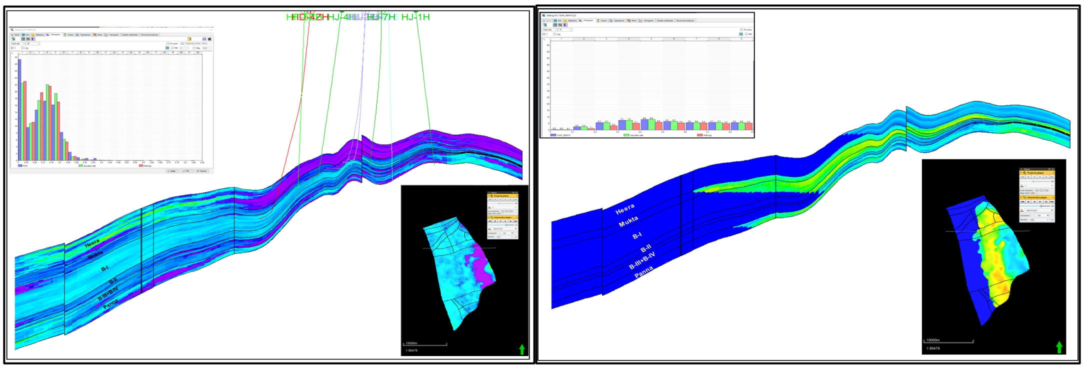

Fig-9. Porosity and Saturation Distribution in West to East Geological Section

Diagenetic Model

Incorporating observations from Sequence Stratigraphy, Depositional Environments, Petrophysical modeling, a conceptual diagenetic model has been prepared. For Panna formation, the less transported/ immature sediments in the basinal lows have moderate to low porosity development while on the other hand more transported/ mature sediments in the Mid Heera and South Heera have good porosity.

In Bassein Formation, Multiple Phases of Carbonate Successions were deposited over Panna Formation or basement due to cyclic rise& fall in sea level. After each phase of Carbonate deposition, sea level dropped causing vadose zone diagenesis, vugs, karstification on exposed part of geomorphic (Inner Ramp/ Shole Zone) highs.

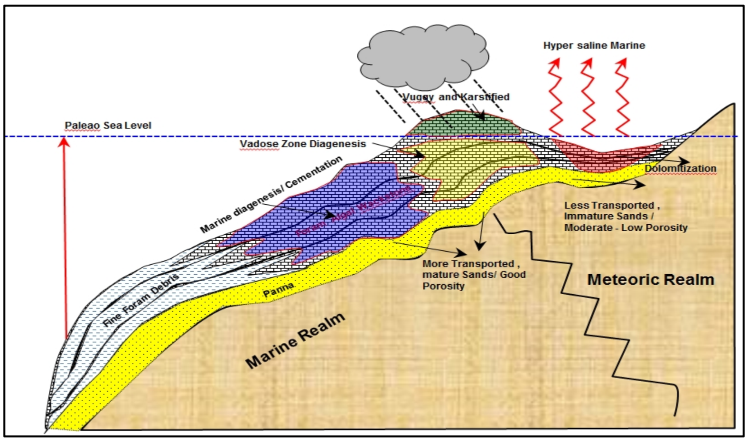

Fig-10. Diagenetic Model of Various Reservoirs in Heera Field

However dolomitization or porosity destructions are attributed to hyper saline marine environment in the adjoining lows. Marine Diagenesis/ cementation also cause the porosity destruction in carbonates deposited in open marine environment. Pronounced unconformity at the H3B lead to very long exposure at the B-I Zone time, where secondary porosity developed in the forms of Vugs & solution channels, but B-II/ B-III karstified layers got filled up due to subsequent mineralization/ precipitation. For Mukta and Heera Carbonates, frequent change in sea level and no long aerial exposure on geomorphic high attributed very poor to moderate porosity development. (Fig.10).

Conclusions

An improvised workflow with integration of various data sets have resulted in a robust static model explaining depositional environment, digenetic history and porosity sweet spots in the Bassein, Panna, Heera and Mukta Formation. The production history from Panna sand in South and Mid Heera explains good porosity development whereas development of porosity in North Heera can be looked as possible area in future. The production from Bassein formation is largely concentrated in the palaeo shoal zone/ geomorphic highs where B-I, B-II, B-III is developed as structural play. The B-IV Zone, Mukta and Heera are Strati-Structural Pay. The production from Mukta and Heera indicates that there are patches of good porosity in and around crestal part of Heera Field.

Acknowledgement

The authors are thankful to Mr. O. N. Gyani, Head-IRS, ONGC, for providing opportunity to carry out the work and permission to publish this paper. They are thankful to Dr. Rajesh Kumar, GM, Head-Offshore-IRS, for providing support and encouragement. Authors are also thankful to Mr. Sudeb Kundu, DM (Res), Mr. Harsha Raghuvanshi Sr. Geophysicist (Surface), Mr. Maheswara Rao Gorle, Sr. Geophysicist(Wells) and members of Neelam & Heera group from IRS, for providing technical support. The authors express their sincere thanks to Shri Rajesh Kumar, DGM- Geophysics (Wells) and Shri I. Dasgupta, DGM (Geol) for providing intellectual support. Special thanks to Mr M. Natarajan, DGM (Geol) and Dr. Alok Thakur, Sr. Geologist for providing valuable data and support from Probe Centre, IRS.

References

G.K. Bhattacharya et al.; “Reservoir Description Studies on Heera Field”, IRS, Jan 1988

Harjinder Singh et al. “Integrated Geo-Celluler Model of Heera to Panna Formation, Heera Field”, IRS, March 2015.

Harjinder Singh et al. “Up gradation of Existing Model of Heera Field in view of New Wells Drilled”, IRS, March 2018 (Unpublished Report)

Petrographic and mineralogical studies of core samples from wells HP-6, HZ-9 and B-38-9, Heera Field, Western Offshore Basin, Probe Centre, IRS. (Unpublished Report)

S. Mahanti, S. Uppal, A. Chakraborty, and R.R. Sharma “Microfacies analysis, biostratigraphic studies and porosity, permeability development of Bassein, Mukta, and Heera formations in Heera and South Heera Fields” , Sedimentology Labortaory KDMIPE, March 2003

Well completion, Log interpretation, Production, WOR, Well testing, PVT, BHS reports issued by Neelam & Heera Asset