

Depositional setup and carbonate reservoir characterization using AI/ML technique: A case study from Western Offshore Basin, India

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Carbonate reservoir characterization, Polarity reversal, Machine Learning

Abstract

Elastic properties of carbonate reservoir and non-reservoir (tight carbonate, shale etc.) may overlap which make it difficult to characterize the carbonate reservoir using conventional interpretation techniques. Artificial intelligence (AI)/machine learning (ML) based approach of G&G data integration & interpretation are making pace in E&P business and is helping a lot to utilize voluminous available G&G data to decipher valuable information. Present study is an example of use of Machine Learning (ML) techniques to delineate the carbonate reservoir in Bassein Formation of Vasai East field of Western Offshore Basin, Mumbai. Bassein Formation of Mid to Late Eocene age is dominated by limestone and proved to be hydrocarbon bearing in Vasai East field. Negative surprises also occurred in the field due to facies variation. Porous limestone of Bassein Formation and intervening/overlying shale with significant overlap in P-impedance could not be discriminated using inversion studies. Although the use of ML approach helped to capture the hidden pattern in data and to delineate the reservoir. A 3-D facies volume was generated using ML technique with three types of facies i.e., porous limestone, tight limestone and shale. Based on the study, polarity reversal due to lateral lithological variation was also identified and mapped. Structural interpretation were refined by incorporating the polarity reversal. Attribute analysis and paleo-structural analysis based on refined interpretation is used to know the reservoir extent. Facies volume along with paleo-structure analysis is used to understand the depositional setup and hydrocarbon distribution in the study area. Results of the study can be used to mitigate the risk in exploration and exploitation of hydrocarbon.

Introduction

Vasai East Field towards the east of South Bassein field, was discovered in 2001 having oil and gas from Bassein Formation. Vasai East Field situated within Central Graben, is part of Heera Panna Bassein (HPB) block. This tectonic block lies in south of Tapti-Daman block and east of Bombay High field. Deccan Trap outcrops mark the eastern boundary while the Vijaydurg graben forms the southern limit of HPB Block. The central graben is the major depocenter, which has accommodated more than 4km sediments. In the eastern part of the study area, central graben is separated from Eastern Homocline by almost N-S trending normal fault (Wandrey et. al.). In the west, bassein east fault is the boundary between central graben and South Bassein gas field (Figure 1).

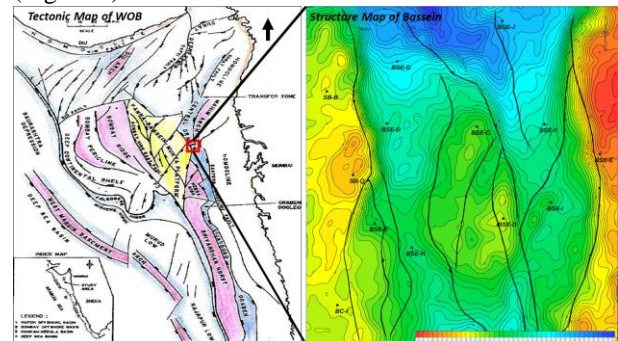
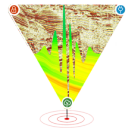


Figure 1: Basemap of the study area along with its regional perspective

The study area is covered by 3-D seismic data for which anisotropic Pre Stack Depth Migration (APSDM) processing was carried out. The objective of the APSDM processing was to take care of the velocity anomalies at shallower levels, causing pseudo structures, especially pull-ups, at deeper levels. This APSDM scaled back to time seismic data



was utilized for the interpretation, attribute extraction and advanced reservoir characterization studies.

Bassein Formation of Mid to Late Eocene age is the most prolific oil and gas reservoir in Vasai East field. This formation is dominated by the limestone (mainly foraminiferal packstone and wackstone) with thin intercalations of shale. Top part of Bassein limestone is porous and charged with hydrocarbon. Additionally, presence of hydrocarbon has been established in Panna and Mukta formations also in this field.

Bassein and Mukta formations of Vasai East field are very heterogeneous in term of lateral facies variation. It has been observed from the well logs that Bassein limestone is porous in the west and tight in the east. Porous limestone of Bassein Formation is overlain by tight limestone of Mukta Formation in the west. Whereas, in the east, top part of Bassein tight limestone is overlain by thick shale at the bottom of Mukta Formation. Due to lack of porosity, wells drilled in the eastern side are devoid of hydrocarbon from Bassein Formation (Figure 2).

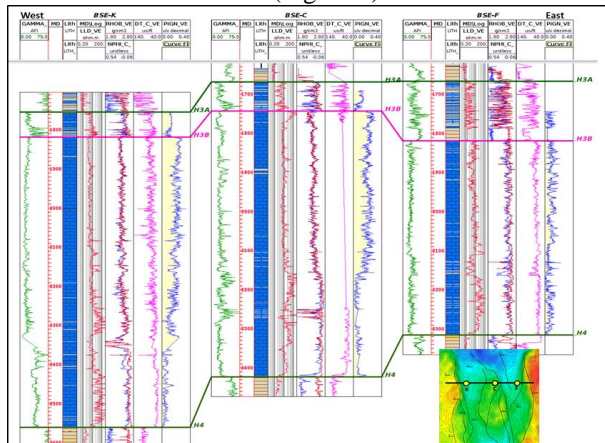


Figure 2: Well log correlation profile from West to East through well BSE-K, BSE-C and BSE-F

Towards the west, Bassein top is transition from hard to soft (Tight Limestone of Mukta Formation to Porous Limestone of Bassein Formation) and corresponds to seismic trough, whereas in the east, Bassein top is the transition from soft to hard (Shale of Mukta Formation to Tight Limestone of Bassein Formation) and corresponds to seismic peak (Bacon et. al). Although to find the boundary of this polarity reversal is not possible without knowing the lateral

facies variation. This problem getting worse towards south where shale at Mukta bottom is thinning. Conventional interpretation method makes it difficult to mark the boundary of facies transition as the P-impedance range of porous limestone of Bassein Formation is overlapping with the intervening/overlying shale (Figure 3). These lateral facies variation, if not taken into account, could mislead the structural interpretation and attribute analysis. Due to overlap in acoustic properties of different facies, it was not possible to discriminate between them using conventional interpretation approach.

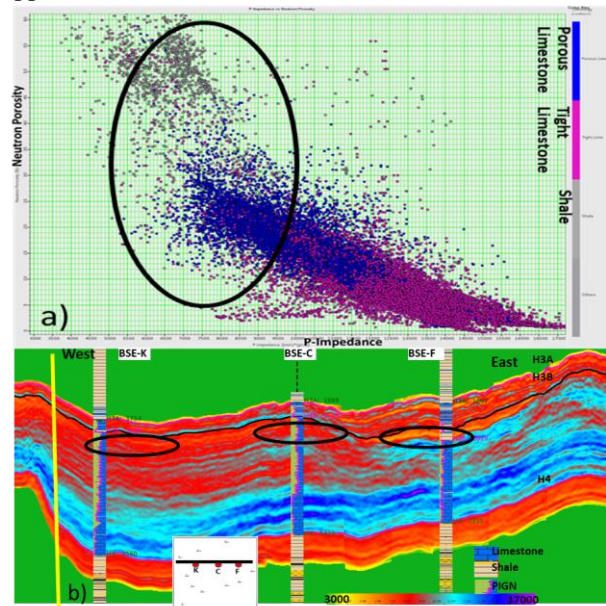
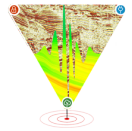


Figure 3: a) Cross plot between P-Impedance and Neutron Porosity colored with facies showing P-Impedance overlap in different facies. b) P-Impedance section along well BSE-K, BSE-C and BSE-F overlain by litho-log and PIGN showing similar impedance for porous limestone and shale.

Artificial intelligence (AI)/machine learning (ML) based approach of G&G data integration & interpretation is helpful to find hidden pattern in data, which is not possible with conventional interpretation. Different seismic attributes provide various information about the geological features of interest in the sub-surface by applying some mathematical or geometrical transformation to the original seismic data. Individually these attributes may provide partial information but together they may supplement each other and may get enhanced by the hidden pattern or information in the data that can



be mined using machine learning/deep learning techniques (Han et. al., Singh et. al.). Large number of seismic attributes may be considered as input to machine learning workflows to mine valuable information and predict variable of importance. Machine learning approach is used to capture the hidden information in the dataset and to generate a 3-D facies volume which have clearly shown the facies variation and helped to identify the reservoir and zone of polarity reversal. Based on the results of ML output, structural interpretation was refined and paleo-structural analysis were carried out, which helped to understand the depositional setup and hydrocarbon distribution in the area.

Methodology

To understand the depositional setup and hydrocarbon distribution in the present study area, following workflow was adopted.

- i) Litho-facies interpretation was carried out for different stratigraphic units.
- ii) Cross-plot analysis was carried out to understand the relationship between elastic properties and lithofacies.
- iii) Inversion studies were carried out to get the elastic properties volumes (P-Impedance, S-Impedance and Density).
- iv) Different seismic attributes based on amplitude, frequency and phase were extracted and analyzed.
- v) ML model was prepared using seismic attributes and inversion volumes to predict the facies volume in 3-D space.
- vi) Predicted facies volume was validated using blind well, which shows good degree of confidence.
- vii) Structural interpretation was refined based on the results of predicted facies volume and considering the polarity change due to lithological variation.
- viii) Paleo-structure analysis was carried out based on refined interpretation and utilized to understand the depositional setup and hydrocarbon distribution.

Log correlation profile (Figure 2) through wells BSE-K, BSE-C and BSE-F is showing three correlated stratigraphic markers i.e., H3A (Mukta Top), H3B (Bassein Top) and H4 (Panna Top) along with interpreted lithofacies. It is evident from the log correlation profile that Well BSE-F is behaving differently in terms of facies and structure. A facies volume can help to understand the lateral facies

variation and depositional set up of the area. Crossplot between P-Impedance and neutron porosity shows that porous limestone and shale are having overlap in P-Impedance range and facies discrimination is difficult on the basis of elastic properties alone (Figure 3).

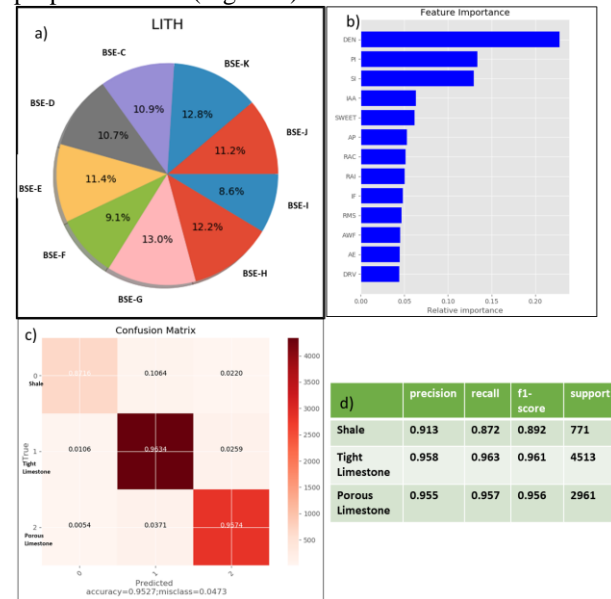
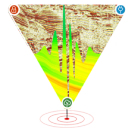


Figure 4:a) Pie diagram showing well wise data distribution used for machine learning. b) Feature importance showing the relative contribution of different seismic attributes and inversion volumes to predict the lithologies. c) Confusion matrix showing the prediction accuracy of machine learning model. d) Accuracy of ML model in terms of precision, recall and f1-score.

To resolve this issue, machine learning approach is used to capture the hidden information in the dataset and to generate a 3-D facies volume which captured the facies variation and helped to identify the reservoir and zone of polarity reversal. Seismic attributes and elastic property volumes were used in training & validation of models and final prediction of facies. Three facies, namely shale, porous limestone and tight limestone were considered for prediction. A porosity cut-off of 12% was considered to differentiate between porous limestone and tight limestone. Model was trained for zone of interest, i.e., H3A (Mukta top) to H4 (Panna top). Nine wells contributed 41225 data labels (lithology) and respective features (seismic and derived attributes) were used for model training, validation and testing. 32980 (80%) data points were used for model training and remaining 8245 (20%) were used as blind testing of the trained model. The input variables



of importance for facies prediction were analysed using feature prediction. Inverted P-impedance and Density were having highest importance. After training the model, it was tested on blind data and prediction accuracies in terms of confusion matrix (Figure 4). The overall prediction accuracy was 95.27 % and miss classification was around 5%.

Well log correlation profile along wells BSE-K, BSE-C and BSE-F filled with predicted facies in between shows the lateral and vertical facies variations. Arbitrary section of predicted facies with interpreted facies at wells has clearly brought out the shale deposited over the Bassein Top in the eastern side (Figure 5). Structural interpretation was refined based on the facies volume and paleo-structural analysis was carried out to understand the depositional setup of the study area.

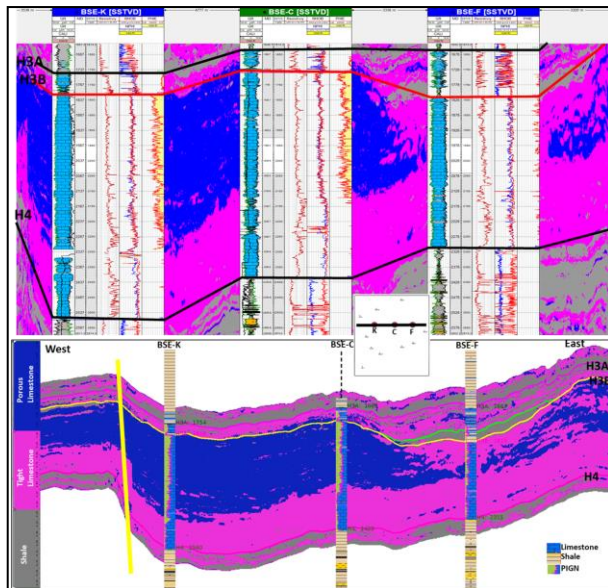


Figure 5: Predicted facies volume along well BSE-K, BSE-C & BSE-F showing lateral & vertical facies variations.

Results and Discussion

Present study has brought out a 3-D facies volume with the application of Machine Learning approach. Analysis of facies volume clearly demonstrates that facies are varying laterally as well as vertically within the formation. It is also evident that thickness of Mukta Formation is increasing from west to east while thickness of Bassein Formation is decreasing.

To understand this, isochronopach maps for Mukta and Bassein formations were prepared and analyzed (Figure-6). Time interval thickness of Bassein Formation ranges from 200 to 380ms, where the maximum thickness is observed in a corridor in the west along wells BSE-G, BSE-K, BSE-H and less thickness observed along the wells BSE-J, BSE-F and BSE-I. The scenario changes when isochronopach of Mukta Formation is analyzed. The maximum thickness was observed now in the eastern corridor along wells BSE-J, BSE-F and BSE-I. The thickness of Mukta isochronopach ranges from 30ms to 130ms.

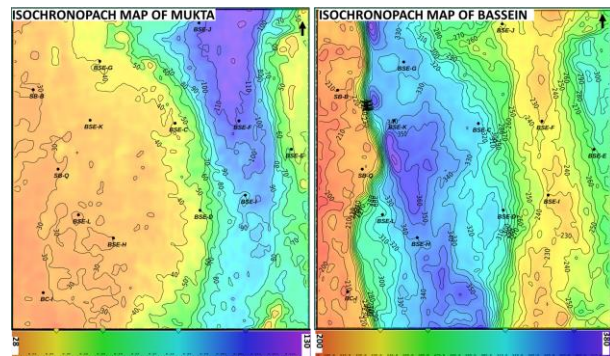
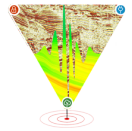


Figure 6: Isochronopach maps of Mukta & Bassein formations showing thickness variation due to erosion.

Facies volume was analysed to understand the erosional-depositional relationship for Bassein Formation and Mukta Formation. Arbitrary line through facies volume (Figure 5) clearly reveals that the upper part of Bassein Formation has undergone more erosion along the corridor of well BSE-F, whereas the Mukta Formation got considerably thick in this corridor, compared to the western side and eastern homocline. The additional thickness of Mukta along the wells BSE-J, BSE-F and BSE-I can be attributed to the more shale deposition over the eroded Bassein Formation.

Due to this erosional-depositional relationship between Bassein and Mukta formations, polarity reversal occurs. Seismic volume in conjunction with facies volume were used to improve the structural interpretation and Bassein top was correlated in dual polarity (peak in the west and trough in the east). Comparison of P-impedance slices before and after considering the polarity reversal in structural interpretation clearly demonstrate that refined



interpretation helped in attribute analysis to demonstrate the reservoir properties, which was not possible if polarity reversal not considered in the interpretation (Figure 7).

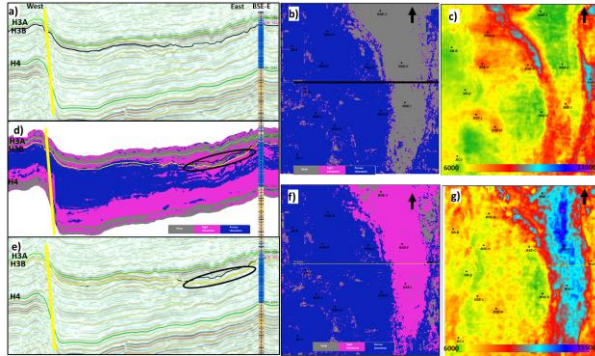


Figure 7: a), b), c) Initial interpretation and corresponding facies and P-impedance slices for Bassein top reservoir without considering polarity reversal. d) facies volume showing shale above Bassein top. e), f), g) modified interpretation and corresponding facies and P-impedance slices.

To understand the hydrocarbon distribution within the reservoir, paleostructural analysis was carried out. Section A (Figure 8) is showing the present-day configuration of the area from Miocene limestone (MLst) to Basement (H5). This section represents the present scenario, where the eastern homocline (towards eastern flank of the section) is structurally higher and Bassein Formation less thick compared to the west. The section B, flattened at H3A (Mukta top), shows the Bassein (H3B) structural configuration at time of Mukta (H3A) deposition, where the thickness of H3A is more in the east compared to the other parts of the field. The flattened section clearly brought out, that the erosion of the top part of Bassein Formation is more adjacent to eastern homocline. Erosion of Bassein Formation along a corridor in wells BSE-J, BSE-F and BSE-I (Figure 6) is more due to long exposure, which has reduced considerable thickness of Bassein and created more depositional space for Mukta (Ghosh et. al.). In the entire study area, Mukta Formation is having the alteration of shale and limestone, whereas the wells BSE-J, BSE-F and BSE-I show thick shale deposition over the Bassein.

Section C is flattened at Miocene Lst top, representing the structural configuration of Bassein Formation at the time of Middle Miocene. Middle Miocene time in western offshore basin was the peak hydrocarbon expulsion phase, hence the relatively

high structures were available at that time got charged with hydrocarbon in this area. Upper Bassein Formation in Vasai East field got charged to the spill point and could not migrate in up dip in along the eastern homocline due to prominent shale thickness of Mukta, which likely played as an effective lateral seal.

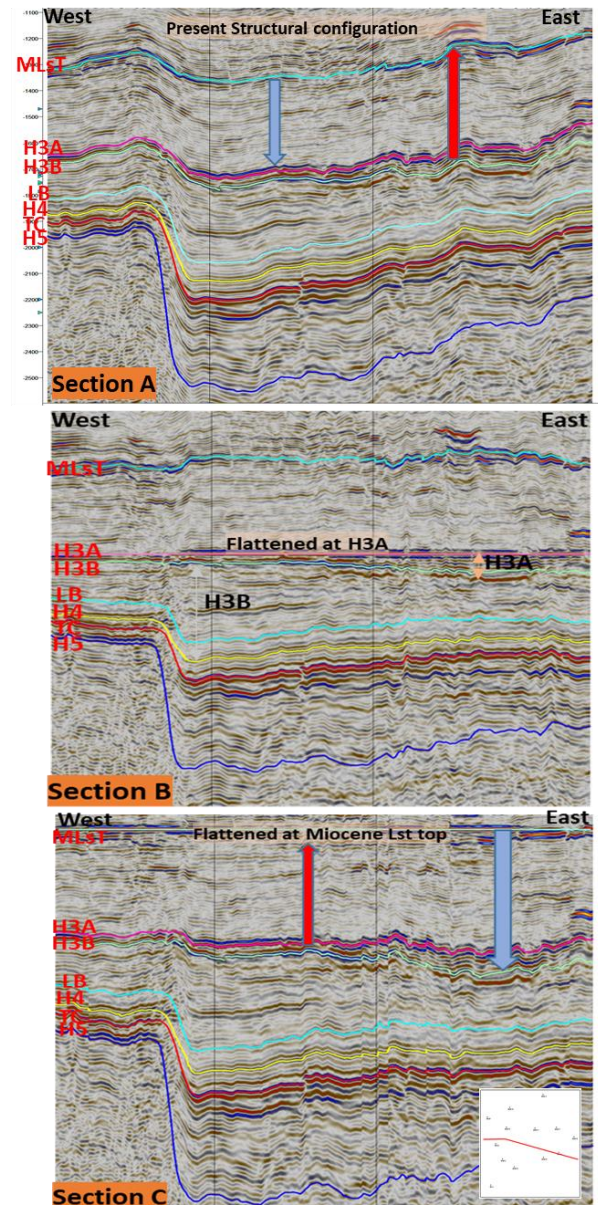
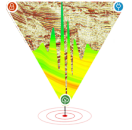


Figure 8: Paleostructural analysis to understand the depositional setup and hydrocarbon distribution in the area.



In the west of Vasai, the structure is relatively low and wells drilled in this part viz. BSE-G, BSE-K turned out to be water bearing.

Conclusions

The data analytics approach of reservoir characterization through reservoir property predictions is an effective approach and it can decipher hidden pattern in the input data, which may not be possible through conventional approach. Creating a system integrating all available inputs in a single platform and process with advanced machine learning methods may help in better understanding of subsurface. In the present study, 3-D facies volume generated using ML techniques, helped to understand the polarity reversal due to lateral lithological variation based on which structural interpretation were refined. Attribute analysis based on refined interpretation clearly brought out the reservoir properties. Paleostructural analysis was carried out to understand the depositional setup and hydrocarbon distribution in the area. This kind of approach can be utilized in other carbonates field having similar complexities.

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