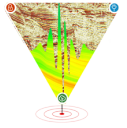




## Application of Seismic Attributes in Delineation and Characterization of Miocene Reservoir-A Case Study from Mumbai Offshore Basin

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**Key Words:** Seismic Attributes, Miocene Reservoirs, Channel, Atoll, Reservoir Characterization.

### Abstract

Delineation and characterization of Miocene reservoirs in the Mumbai Offshore basin pose multiple challenges as their lithology and petrophysical properties vary greatly not only with their depositional environment but also with the post-depositional diagenetic process. Independent analysis of each of the processes is required to address the complexities of such reservoirs. Clastic channel reservoirs of the Miocene age along with carbonate reservoirs have been established in the basin and the depositional environment plays a great role in the distribution of lithological/petrophysical properties within the reservoir. Thus, a prior understanding of geomorphology may provide valuable information for the characterization of the reservoir. 3D seismic attributes such as, variance, curvature, sweetness, and spectral decomposition were used for the identification of channel geometry and fault patterns. Seismic attributes were also utilized for the characterization of the carbonate reservoir. Based on the analysis, a conceptual geological reservoir model of the atoll phase reef was envisaged. Further, seismic interpretation in the Wheeler domain and post-stack inversion was also performed which reinforced the envisaged geological model. Recently, one well was drilled which was falling on good facies in the envisaged model and it encountered better facies development as anticipated from the model.

### Introduction

3D-seismic attributes and their applications in oil and gas industries have evolved extensively in the last three-four decades. 3D seismic data enabled the seismic attribute analysis in the planer domain which resulted in capturing of paleo geomorphological features (Posamentier et al., 2000). These geomorphological features can be utilized for exploration and development studies (Posamentier et al., 2004). But most of the work is confined to the clastic environment due to its uniformity of features such as fluvial channel system, levee, bar, turbidites etc. (Posamentier et al., 2000, 2004, 2006; Nordfjord et al., 2005). Also, the petrophysical properties of reservoirs formed in similar clastic environments have a strong correlation. The same cannot be said about the carbonate reservoirs as their petrophysical

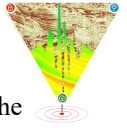
properties depend upon multiple factors including depositional environment, and diagenetic and post-diagenetic processes. Due to such complexities, carbonate reservoir characterization also becomes challenging. By utilizing the seismic-derived geological features, the carbonate reservoir may be characterized properly. The paper demonstrates the successful application of seismic attributes in the delineation of the Miocene channel and characterization of the carbonate reservoir.

### General Geology of the Area

Mumbai offshore basin is situated on the western continental margin of India. It is a pericratonic rift basin. In the North-North-East it continues into the onland Cambay basin. It is bounded in the northwest by Saurashtra peninsula. In the north, it is bounded by Diu Arch, while in the northwest it is bounded by the Saurashtra peninsula. Basin's southern limit is marked by the east-west trending Vengurla Arch to the South of Ratnagiri and to the east by the Indian craton. The Mumbai offshore is divided into several structural provinces with different stratigraphic and tectonic events that can be identified within the basin. These are; the Diu and Tapti-Daman blocks in the north, Heera-Bassein block in the east-central, the Mumbai Platform-Deep Continental Shelf and the Shelf Margin Sub-basin in the mid-western, and the Ratnagiri block in the south. The tectonic map of the basin is shown in figure-1. The study area lies in the Heera-Bassein Block close to the junction of Diu fault and Central graben west fault.

In the area of study, the basement is predominantly basaltic with patches of granitic basement in a few areas. More than 4000 meters of thick sedimentary sequence from Paleocene to Recent age is resting over the basaltic or granitic floor of Late Cretaceous or Precambrian age respectively.

The Basement is non-conformably overlain by the clastic Panna formation of Paleocene to Early Eocene age. Panna formation is overlain by Bassein formation of Middle to Upper Eocene in age. The Mukta formation of Early Oligocene age unconformably overlies the Bassein Formation. The Mukta formation is conformably overlain by limestone-shale alternation of Heera formation of



Early Oligocene in age. The Heera formation is unconformably overlain by Alibag formation of Late Oligocene age.

in the study area. The generalized stratigraphy of the Mumbai offshore basin is shown in figure-2.

**Methodology**

The well-log correlation was carried out and major markers along with the Miocene carbonate reservoir were correlated. The well-seismic tie was carried out and multiple horizons were mapped using 3D seismic data. 3D seismic attribute volumes such as variance, sweetness, etc. were generated. Horizon corresponding to S1 top, and Miocene carbonate pay top/bottom were used to extract horizon-based attributes of various seismic attribute volumes. Seismic interpretation was also carried out in the Wheeler domain to interpret data in true geological time and space. Post stack inversion was performed to understand qualitative facie distribution. Well-logs and seismic attribute analysis were integrated to generate the geological model. Based on the model, better reservoir facies zones were identified.

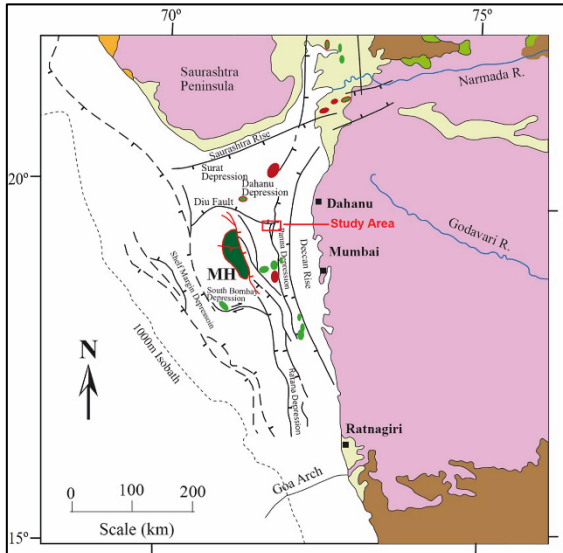


Figure-1: Regional tectonic set-up of the Mumbai Offshore Basin (Modified after Rao & Talukdar 1980; Biswas & Deshpande 1983; Wandrey 2004).

**Well Log Analysis**

Vertical wells A, B, and C were drilled for the exploration of multiple pay targets and regional geological analysis. While the well-D and well-E were development wells drilled from platform-P. The basemap of the study area is shown in figure-3.

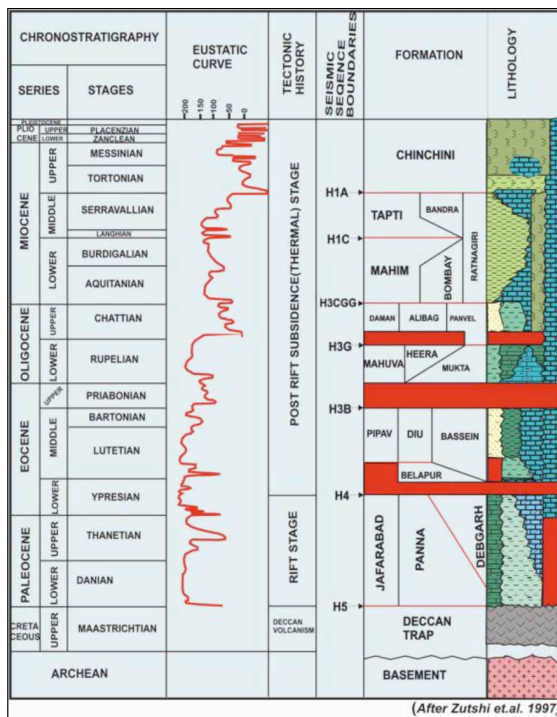


Figure-2: The generalized stratigraphy of the Mumbai offshore basin.

Bombay formation of the Lower Miocene age overlies the Alibag formation. The Bombay formation is overlain by as Mahim Formation and the Mahim formation is overlain by the sequence of Late Miocene to recent age known as Chinchini formation. The paper deals with Miocene reservoirs

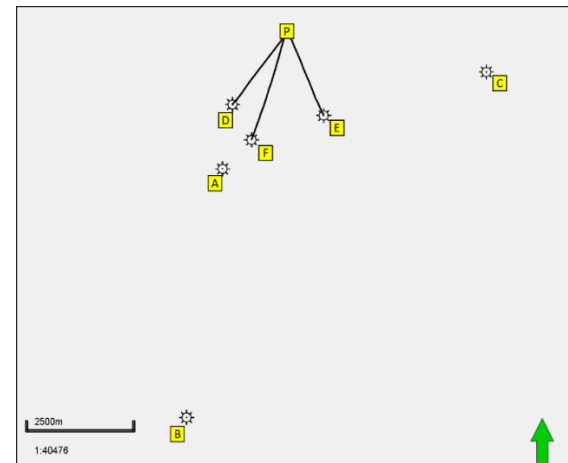
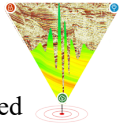


Figure-3: Basemap of the study area with wells.

Well-A, D, and E encountered Miocene carbonate reservoir, while well-B and well-C did not have Miocene carbonate reservoir development. S1 channel sand is not encountered in these wells. These wells were used for the assessment and characterization of Miocene carbonate reservoir. The well-log correlation of wells having the carbonate reservoir is shown in figure-4. Well-based pay thickness map was also generated (Figure-5). One the basis of the pay thickness map, well-F was drilled and it was expected to encounter good facies development. But it encountered only four meters of



net pay thickness due to deterioration of facies quality.

To address such sharp facies deterioration, seismic attribute analysis was carried out.

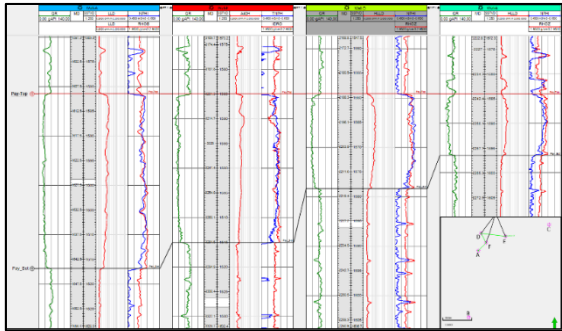


Figure-4: well correlation of wells A, F, D, and E (from left to right)

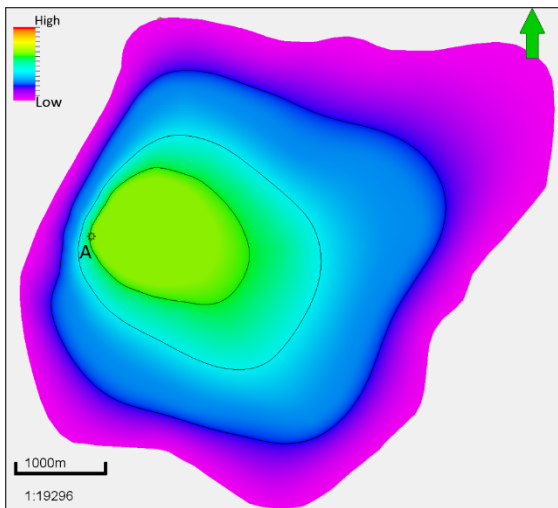


Figure-5: Well based pay thickness map of Carbonate reservoir.

### Seismic Interpretation

Multiple horizons were mapped and structural attributes were generated for fault interpretation. Seismic section with the mapped horizon H1C, Mahim top, Heera top, Panna top, and interpreted faults is shown in figure-6.

At the deeper Panna level, major NS and NW-SE trending fault trends were identified using the variance attribute. Shear-induced faults were observed from the Mahim top (their prominence can be seen from the H1C level) to the shallower Chinchini formation. These faults were generated due to the beginning of the hard collision of the Indian plate with the Eurasian plate.

The hard collision started from Late Oligocene to the Early Miocene period (25–20 Ma) (Hinsbergen, 2012). Figure-7 shows the variance attribute extracted at H1C top and at the Panna top which

captures shear-induced faults and basement-derived faults.

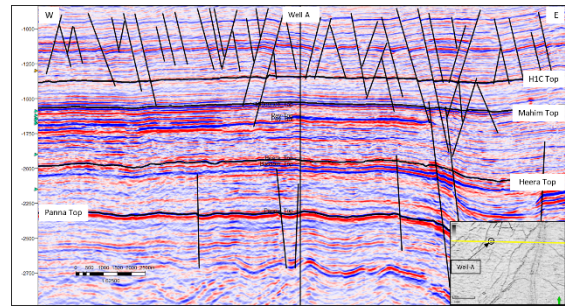


Figure-6: Seismic section along interpreted horizon and faults.

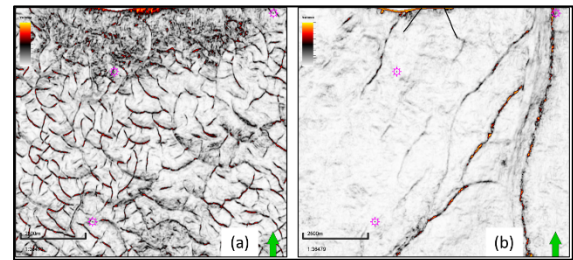


Figure-7: Variance attribute extracted at (a) H1C, (b) at Panna (H4) Top.

### Seismic Attribute Analysis

S1 channel sand and carbonate reservoirs of Miocene age are well established in Mumbai offshore basin. Detailed attribute analysis was carried out for extracting structural and geomorphological features within Miocene.

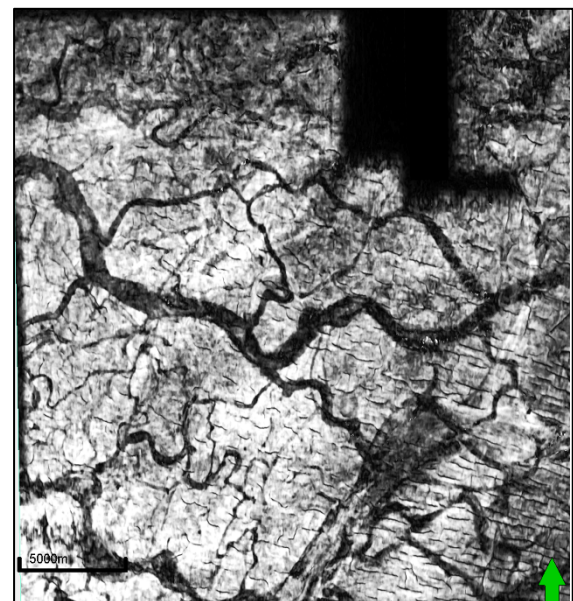
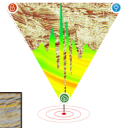


Figure-8: Mean of the sweetness attribute was extracted using S1 top plus 10 ms window.

Seismic attributes such as absolute amplitude, reflection strength, and sweetness were generated to



extract reservoir geomorphology. The mean of sweetness attribute was extracted using S1 top with 10 milli second window. The attribute captures the detailed S1 channel along with its smaller distributaries (figure-8).

The carbonate reservoir is the main objective of the paper. In the well-log correlation (figure-4), it can be observed that among well-A, D, E, and F that the best reservoir facies developed in well-A and poor facies developed in well-D, and E (figure-4). Well-F which is closest to well-A was drilled on the basis of the well-based pay thickness map. It was expected to have better facies development but encountered poor facies development. While it had a good gross thickness but poor porosity was observed and it had only a few meters on net pay. Seismic attribute analysis was carried out to minimize the uncertainty in the facies distribution. Attributes such as rms, sweetness, spectral decomposition, etc. were used to capture facies variation.

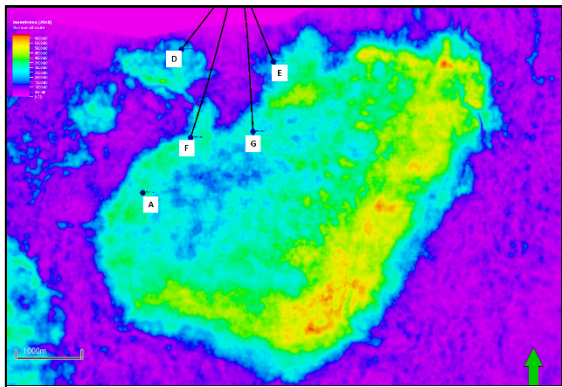


Figure-9: The mean of sweetness attribute was extracted using the reservoir top and bottom.

Various horizon-based attributes were also extracted using Miocene carbonate pay top and bottom horizons.

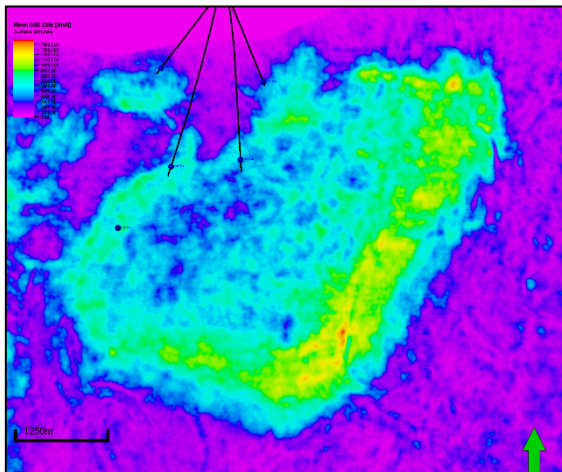


Figure-10: Mean of iso-frequency volume of 22Hz extracted using reservoir top and bottom.

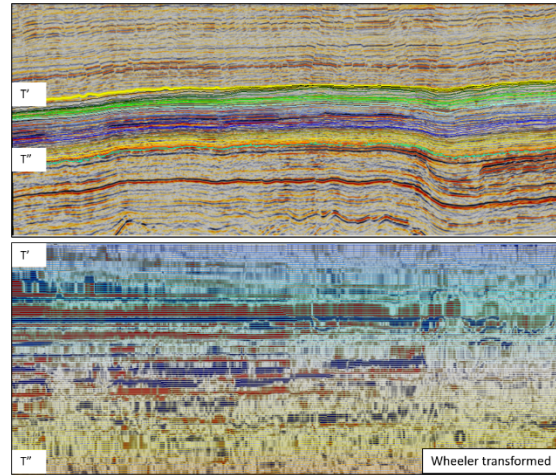


Figure-11: seismic data in the time domain and in the Wheeler domain (from event T' to T'')

Figure-9 shows the sweetness attribute extracted from Miocene carbonate pay top to the bottom which resembles Atoll phase reef development. Spectral decomposition was carried out and an iso-frequency volume of 22Hz was generated. The mean of spectral decomposition volume was extracted using the Miocene carbonate pay top and the bottom (Figure-10), which shows a similar feature as the sweetness attribute.

To further ascertain the atoll model, seismic attribute analysis was carried out in the Wheeler domain. Converting seismic data in the Wheeler domain requires closely tracked horizons that can capture layers within seismic resolution. These horizons were generated in two stages; first, major events were mapped and then the proportional horizon method was used to fill in-between horizons. These horizons were then used to convert seismic data into the Wheeler domain using OpendTect software (Brouwer Friso, 2008) (Figure-11).

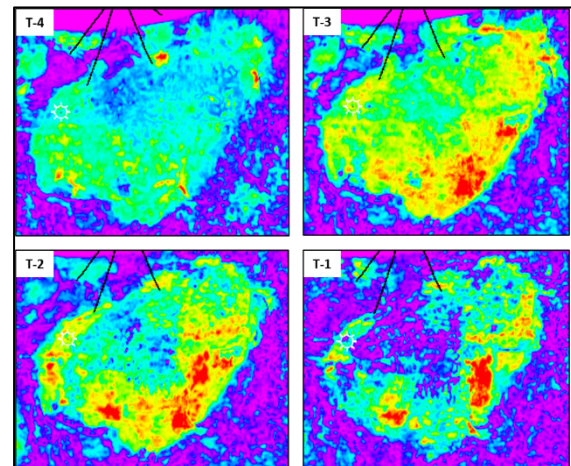
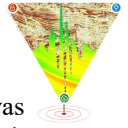


Figure-12: Phase-wise development of Atoll from bottom to top (T4 to T1) observed in Wheeler domain.



The Wheeler domain converted volume was used to generate sweetness volume and it was analyzed in time slices which represent geological analysis in true depositional time and space. The time slices clearly brought out the phase-wise development of the Atoll (Figure-12).

Post-stack deterministic inversion was also carried out and mean of p-impedance was extracted using Miocene pay top and bottom. Figure-13 shows the rim of the carbonate having similar impedance values, resembling a classic atoll feature.

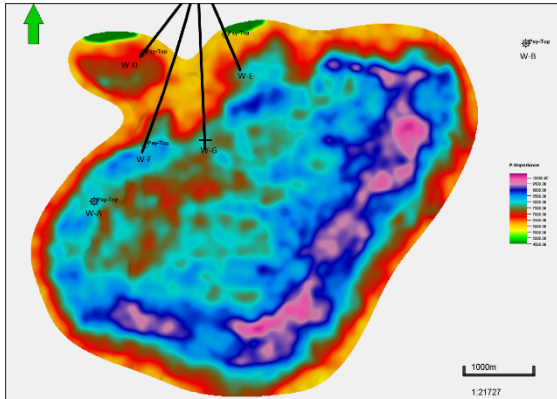


Figure-13: Mean of p-impedance showing Atoll like feature.

An atoll reef model was envisaged based on the seismic attributes and analysis in the Wheeler domain. Atoll has primarily three zones; fore-reef, reef-crest/flat, and lagoonal area.

The porosity is best developed at the reef crest while fore-reef and lagoonal areas have relatively poorer facies. The envisaged geological model is shown in figure-14. Well-A falls in the reef crest area and hence best facies development is observed. While Well-D, E, and F fall in the fore-reef area having relatively poor facies.



Figure-14: An envisaged geological model of the Atoll.

Well-G was drilled after the analysis and it was falling in the reef crest area of the envisaged model. As per the envisaged model, Well-G was expected to have very good reservoir facies development. After the drilling, well-G encountered much better reservoir facies development than well-F (which falls at the fore-reef area). The log motif having gamma ray log, neutron-density, resistivity, water saturation, effective porosity, and lithology of well-G is shown in figure-15.

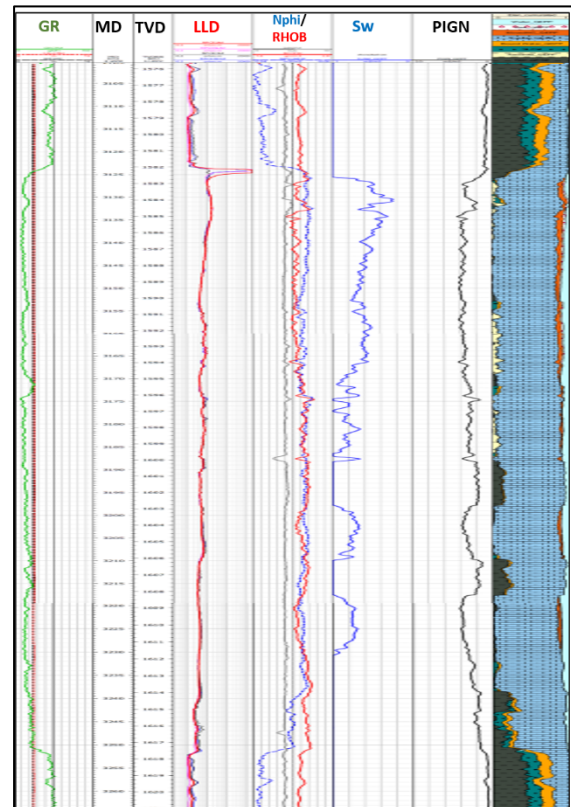
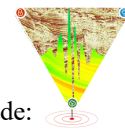


Figure-15: Log motif of well-G, showing good development of Miocene carbonate reservoir.

### Conclusion

The paper uses seismic attribute analysis both in the conventional time domain and in the Wheeler domain to understand the geomorphological features of Miocene reservoirs. Shallow Miocene shear-induced faults along and deeper basement-controlled faults were brought out. High definition S1 channel along with its distributaries was detected using horizon-based attributes. The Miocene carbonate reservoir was characterized using seismic attributes, inversion, and seismic analysis in the Wheeler domain. Based on the analysis, the carbonate reservoir was identified as an atoll phase reef reservoir. The best facies development zone was identified in the reef-crest area. The model was also validated by the newly drilled well which falls in the reef-crest area and encountered high net pay thickness. The paper demonstrates the successful



impact of seismic-derived geological models in field development planning.

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*Views expressed in the paper are the opinion of the authors and do not necessarily reflect the opinion of the ONGC.*

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