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# Landmark achievement from Unconventional Reservoir - A case study in Mumbai High Field

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## Abstract

Oil indication in unconventional reservoirs like Basement and Basal Clastics was known by 1986-87 in Mumbai High field after drilling of few exploratory wells. After a gap of more than two decades, an attempt was made to exploit oil from these deeper prospects to enhance the oil production from field. Initial well-A was drilled in prospective area for Basement and Basal Clastics, but could not flow.

Basement is unique and unconventional in the context of reservoir nature and hence complex to characterize and isolate the prospective areas. Hydrocarbon accumulations are seen in the fault zones and its associated interconnected network of fractures by which post depositional porosity and permeability are generated.

Well data analysis suggests that wells drilled away from fault zones are devoid of hydrocarbons whereas some wells drilled over the structures or close to faults struck hydrocarbons. The seismic data analysis might suggest that the faults and fractures are associated with anomalies in amplitude or impedance, which may not be directly attributed to only them as non-fractured heterogeneities in sub surface could be the source of such anomalies. Hence, integrated approach of analyzing available G&G data and especially the seismic attributes is essential for evolving a working strategy to realize the potential of Basement oil exploration.

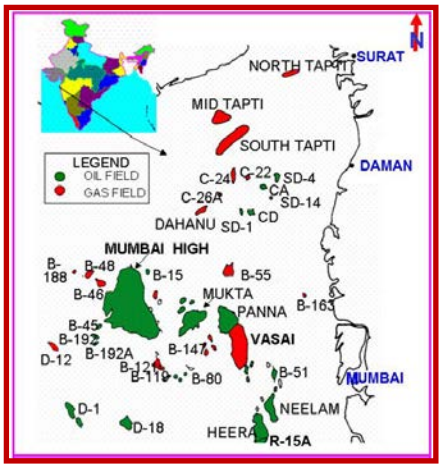



**Figure 1: Index Map of Mumbai High Field**

In this paper, an attempt has been made to integrate 3D seismic data with available G&G data coupled with production data of Mumbai High field. It has brought out mapping the detailed Basement fault pattern and the probable locales of fractured basement reservoir prospectivity. A suite of attributes having capability to predict the discontinuity and show their lineaments were generated. The analysis shows that two attributes namely Variance attribute and Ant tracking to be the best fit among the lot for predicting.

The tectonic style and fracture architecture governs the success of unconventional reservoir Basement and Basal Clastics. Integrated G&G approach using new generation technologies, modeling G&G data with special emphasis to identification of fracture network had led to the success of production of Well-B from the field.

Identification and accessing the area was a great challenge. But with the proper analysis, monitoring coupled with new technology; the well was successfully completed and started producing @1860 bbls oil, the highest per well production in current scenario.

## Introduction

Mumbai High Field is a giant, NW-SE trending, doubly plunging anticline structure with its conspicuous eastern faulted limb and is within an average water depth of 70m. It is situated in the western offshore of India, this field is producing hydrocarbons primarily from multilayered Lower

Miocene carbonate reservoirs and the fractured Basement and Basal clastics as secondary reservoirs (Fig-1). Although commercial accumulation of hydrocarbons from naturally fractured Basement and Basal Clastics reservoirs have been established in the Mumbai High Field quite early in the field history, focused efforts to exploit the full potential of this Unconventional Reservoir have taken pace recently.

Oil exploration has become more difficult, mature and new discoveries have become a rarity. The ever increasing of energy demand has to be met with increased production from unconventional reservoir like Basement and Basal Clastics. It has got importance in recent time and focus is there to understand the origin, occurrence, distribution and commercial potential, which has led to a comprehensive understanding of the various aspects of the Petroleum system of this unconventional reservoir.

Basement rock is naturally fractured reservoir is significantly influenced by the characteristics of the fracture network. It is unique and unconventional in the context of reservoir nature and hence complex to characterize and isolate the areas of interest, which controls the volume and flow direction of the hydrocarbon through the hosting layers within unconventional reservoirs. Detailed knowledge of fracture characteristics allows the design of well paths that intersect a larger number of permeable fractures, thus increasing production and enables prediction of preferential flow paths. A good understanding of the fracture network in terms of intensity, orientation, and spatial distribution is therefore essential for both well planning and reservoir development.

The structural configuration, petrophysics and production data are available at discrete points in the field. 3D Seismic data and its attributes act as a bridge in the area between the drilled wells and it decodes the structural configuration, fault distribution, different petrophysical parameters Basically, in seismic data we get the composite response of various layers / lithology's in terms of amplitude, phase and frequency. These responses are the combined effect of lithology, porosity, fluid content, lithification or cementation, discontinuities in term of fault & factures and depth of burial. Before planning re-location of well-A to new location dealt in this paper, the task was identification of favorable locale in the field to exploit the hydrocarbon from unconventional reservoir which was missed in well-A. Before firming-up the location it was of paramount importance to integrate all available data, related their characteristics and evolve a workable model in order to drill in the good reservoir part.

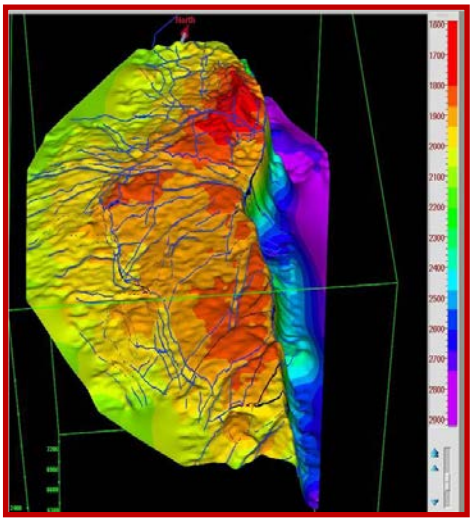
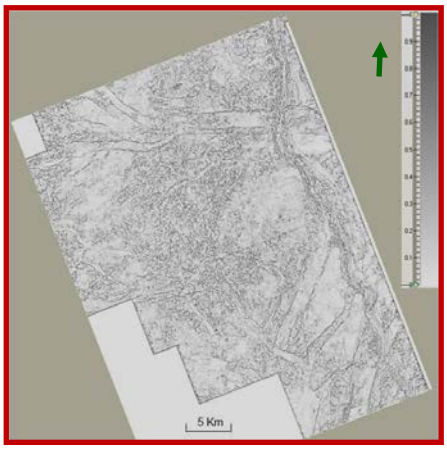


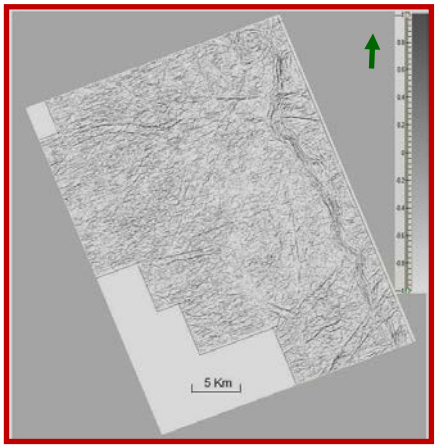
**Figure 2: Mumbai High Basement Relief map**

The orientation and nature of the in-situ stress field and pre-existing natural fracture networks in the reservoir are amongst the critical parameters controlling the success of Unconventional reservoir. It is expected that high density of fractures is found in the vicinity of the major eastern faults in Mumbai High (Fig. 2). The two major factors influencing the development of fracture systems viz; the tectonic history and its composition. The associated fracture zones often display subtle expressions in seismic data, but seismic attribute and visualization techniques are helping in identification and characterize them.

In this paper, we attempt to integrate 3D seismic data with available G&G data coupled with production data of Mumbai High field. It has brought out the detailed Basement fault pattern and the probable locales of unconventional reservoir prospectivity. Special emphasis was given on the seismic attributes capable of identification of natural fractures and their origin and relationships to fault systems and the tectonic, lithologic and stratigraphic variables that control their distribution in order to evolve a working strategy to realize the potential of Basement oil exploration. A suite of attributes which are supposed to possess the capability to predict the discontinuity and show their lineaments were generated. The analysis of each attribute along with other available geoscientific data was done to understand the fault and fracture network. The analysis shows that two attributes namely Variance attribute and Ant tracking to be the

best fit among the lot for predicting. The NS trending Mumbai High East fault is the major tectonic trend along which the higher fracture density is inferred (Fig. 3 & 4).




**Figures 3 & 4: Showing the Variance and Ant tracking attribute slice in Basement section in Mumbai High South**

## Geological Framework

The Western Offshore Basin of India is located in a passive margin set up. The entire shelf is split into longitudinal strips by a number of Basement controlled faults, which resulted in horsts and grabens. The largest Basement uplifted feature is Mumbai High (MH), with Tertiary carbonate hydrocarbon as main reservoir. The field is giant paleohigh of the Precambrian granitic rocks overlain by Deccan Traps at some parts and clastics & carbonates over the greater part of the area. The drilled well data indicates the basement rocks of varied lithlogy consisting of granite gneiss, biotite schist, phyllites and basalts. Structural fabric is constituted by rift related basement horst and graben features draped by carbonate- clastic sediment cover strongly disrupted by multiple sets of faults. Mumbai High has mainly four conspicuous fault trends (Fig. 5), namely NW-SE trending Dharwar rift phase, NS to NNE- SSW Aravalli Trend, ENE-WSW fault set corresponding to Narmada trend and NNE-SSW fault sets reactivated during the Tertiary strike slip regime that resulted during the northward plight and the attendant anticlockwise movement of Indian Plate, as evident from the G&G studies (Verma.N.K. etal 2001). Most of the faults as observed are parallel to sub-parallel to these main trends. The basic structural architecture of Mumbai High is characterized by the imprints of these four major tectonic episodes witnessed by the basin.

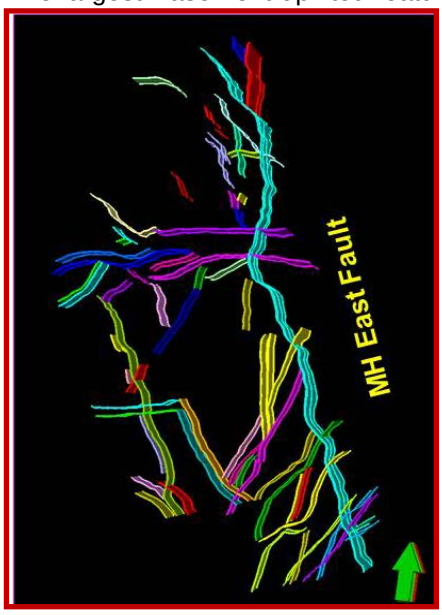



**Figure 5: Major Tectonic Trends in MH**

The studies of different authors bring out the Mumbai High as a paleo high with syn-sedimentary faulting. The rifting and block movements caused due to extensional tectonics gave rise to prominent highs. One such structure, Mumbai High, remained exposed till Oligocene times. Later the sedimentary sequences covered the basement rocks by the transgressive phases. The weathering due to longer exposures, alterations of mineral constituents, faulting and fracturing by tectonic processes, might be some of the reasons for the development of secondary porosity and permeability, and thereby forming a good reservoir.

## Conceptualization of the Methodology

The conventional 3D seismic mapping describes the tectonic architecture on a large scale and provides an idea of the overall stresses that initiated the structural features within the basin (Fig. 6). 3D seismic attributes have proven to be amongst the most useful geophysical techniques for characterizing faults and fractures (Chopra and Marfurt, 2007; Backé et al., 2011). A seismic attribute is a quantitative measure of a seismic characteristic of interest.

The study and interpretation of seismic attributes provide us information about the geometry and the physical parameters of the subsurface. Whereas, Seismic attributes is to provide accurate and detailed information about the reservoir. The usage of seismic attributes depends on the knowledge and understanding and for what reason it is being used.

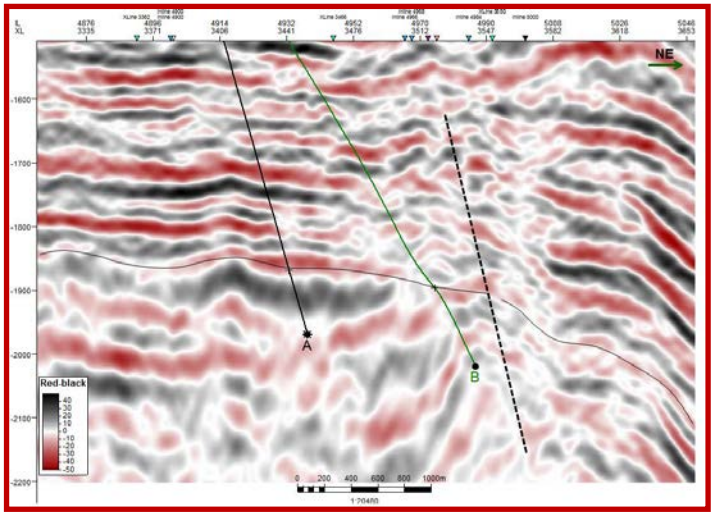



**Figure 6: Seismic section passing through Well-A and Well-B**

The presence of fracture in the basement reservoirs is a boon as it given secondary porosity. The intensity of faulting is generally higher in the Granite/ Metamorphic terrain as compared to the younger Basaltic flow and the role of weathering is more dominant in the top part basement. The study area falls is Granite terrain, hence the 3D seismic data coupled with seismic attributes namely variance attribute and ant tracking have proven most successful at delineating features that are mostly faults and/or fractures. Variance is calculated in three dimensions and represents the trace-to-trace variability over a particular sample interval and therefore produces interpretable lateral changes in acoustic impedance (Aguado et al., 2009). Similar traces produce low variance values, while discontinuities have high values. Because faults and fractures cause discontinuities in the neighboring lithology's and in the trace-to-trace variability, they become detectable in 3D seismic volumes; this attribute is useful for edge detection. One of the most used attribute in the industry is ant tracking it enables for fast extraction of fault networks. This attribute follows an analogy of the behavior of ants, as they choose the shortest path between their nest and food. During the process, a large number of electronic ants are distributed in the 3D seismic volume & allowing them to move along faults and emitting pheromones. Surfaces that are strongly marked with pheromones are likely to be faults & fracture zones.

The structural style and lithofacies architecture dictate the reservoir heterogeneity of Mumbai High field (Fig. 1) in western offshore, India. Mumbai High Field is under a redevelopment campaign. The 3D seismic data is an integral part in G&G model of the field. The model is being continuously refined and updated with additional input of well data. Having said that, it is also imperative to point out that the unconventional reservoir should be taken with due diligence because the experience in the field shows that if the well is placed in tectonically disturbed area; the chance of success is high. An attempt was made to look into seismic data attributes, and to understand the relationship between the seismic attribute, reservoir facies and fracture network for unconventional reservoir.

## Case Study and Discussion

The study comprises of integrated analysis of geological, geophysical, well and production data. The importance of structure and faults and its associated fracturing with respect to hydrocarbon accumulations in Basement and Basal Clastics is a key to success. Faults are identified on vertical sections by taking the clue from the geometric attributes volumes, as it helps in identifying the faults and stratigraphic features. Extracted variance and ant tracking attributes along the Basement surface brings out alignments discontinuous zones that deciphers the major and minor faults thereby the zone of fractures.

It is a well-established fact that all basement highs are uplifted over a period of time and exposed for a long geological time. The sediments much younger deposited in the flanks and over the highs provide the source and seal mechanism for basement play. This indicates that the oil generated in the flank sediments move to the slopes/highs and the overlying sedimentary sequence takes care of seal role. This is almost the case with Mumbai High which formed due to rifting and fault block movements along NNW-SSE trending faults and exposed till Oligocene times. The basement rocks are overlain by Lower part of Middle Miocene units and flanked by younger Eocene sedimentary sequences, thereby forming a good candidate for striking hydrocarbons. In this case one can observe the severe faulting

which might have acted as conduits for hydrocarbons generated in the adjacent flanks in the younger sequences to migrate into favorable locales. These faults have created fractures as faults are the fracture drivers (Fig. 4). The basement rocks are hard and brittle with very low matrix porosity and permeability. The development of secondary porosity in Basement may be due to two reasons, one is tectonic porosity due to joints, faults, fractures, etc. and the other is dissolution porosity due to solution effects in weathering zones or fault zones and effects combined with hydrothermal circulation. The Basement core data studies reveal the fact of the presence fractures filled with hydrocarbon in well-C and based on this lead well-A was drilled for Basement and Basal Clastics prospect.

The well-A was drilled down to 100m (TVD) within Basement, but the well didn't flow. It was decided to analysis the well data coupled with available geoscientific data and if possible relocate the well in better place through sidetrack for Basement prospect. For this 3D seismic data was first conditioned by smoothing and then the variance attribute volume was generated, then with this volume ant tracking volume was further generated. 'Variance attribute' helped in the estimation of local variance in the signal thereby helped for edge detection, while the 'Ant-track attribute' helped in aligning/joining the discontinuities encountered in the variance volume. Thus it clearly brings out the fracture network and their orientation. This attribute has been used to identify the possible discontinuity trends so that wells can intersect maximum discontinuities.

The variance attributes slice corresponding to Basement section around the well-A were taken and it clear demonstrate by sharp edges shown in the slices, it is observed that the variance are noticed more prominently lineament of below 50 to 75 m from Basement top (Fig. 7) nearer to Eastern boundary fault. The slice clear indicates faults and thereby associated fractures are development in the eastern part from well-A, it very conspicuous that these lineaments are absent in well-A. Similarly the ant tracking attribute slice generated from the volume shows the alignment of discontinuities is prominent below 50 to 75m from Basement top (Fig. 8). The lineaments are NW SE to NS trending which is imprint of Dharwar rift phase and Aravalli trend respectively. The variance located in the vicinity of Mumbai High (MH) east fault and the associated fault sets indicating probable fracture development. It is a major zone of deformation comprising several faults which are offset by minor ENE-WSW cross faults. It can be well appreciated that the Variance and ant tracking cubes has the potential to bring out areas of probable higher fracture density.

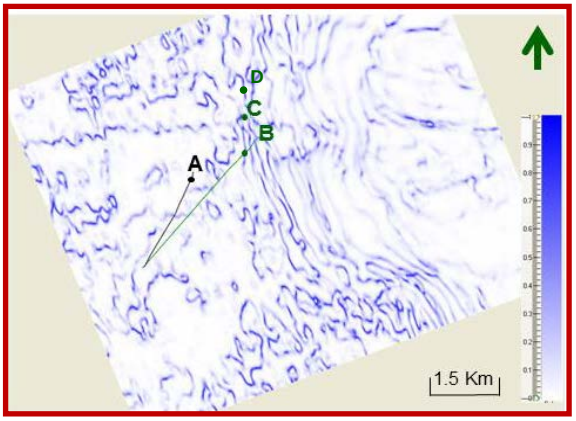



**Figure 7: Variance attribute slice within Basement**

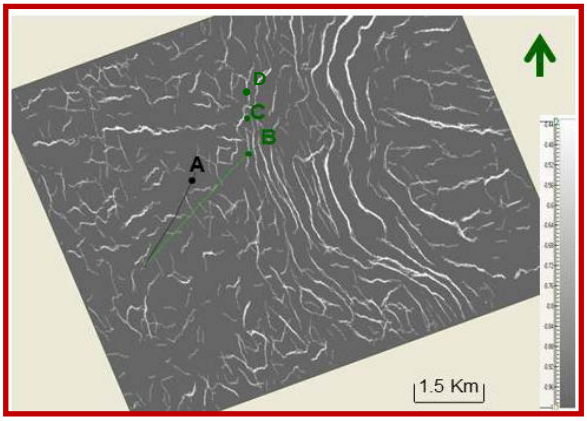



**Figure 8: Ant tracking attribute slice within Basement**

The area which appeared to be interesting in both the attributes, is in the east of well-A, close to main eastern boundary fault, approximately 1.5 km laterally away from well-A. Now the task of relocating the well-A by sidetracking was a great challenge, since the area appeared interesting is more than 3.2 km away from the platform. But, using latest technology of expandable casing, hole enlargement at angle 71 degree and mud systems like SOBM & HGS could enable us to successfully sidetrack well-A as well-B & achieve desired horizontal drift of 3365 m. Basement top was encountered at 1896m and 340 m section of Basement (120 m TVD) was drilled down to a depth of 4310 m. FMI & Sonic Scanner logs recorded against the granitic Basement indicate a high-angle/oblique-fracture network. A proper analysis and planning prior to drilling of a well is of paramount importance in order to produce optimally. Thereby, reducing the uncertainties of predictions made for focused exploitation of hydrocarbons especially for unconventional reservoir. The well was successfully completed and started producing @1860 bbls oil, the highest per well production in current scenario.

Thus the integrated analysis of the attributes along with well data has enabled the identification favorable locale. These attributes has helped to identify the possible discontinuity trends so that wells can intersect maximum discontinuities. Predictability of fracture trends and thereby the identification of favorable locales for basement exploration can be rated as moderate to high in Granitic and metamorphic basements. Another well-D was drilled recently has further validated the model.

## Conclusions

The Basement in Mumbai High structure is not too deep and occurs in the range of 1700 – 2000 m and hence focused and exclusive for Basement and Basal Clastics exploration is required as the field has established hydrocarbons for unconventional reservoir. The case study of wells-A & B has clearly brought out that the predictability of fracture trends by attribute analysis and thereby the identification of favorable locales is key to success. This has further validated by the success of well-D. The wells should be targeted in the maximum damage zone/major fault zone, as they are probable locales of high stress concentration and therefore will have higher fracture densities especially in Granitic terrain. Further in order to exploit the full potential of Basement reservoirs, drilling of high-tech inclined wells and completion needs to be for proper planning of the wells, especially in offshore setup like Mumbai High.

This resounding and landmark achievement was the result of skillful analysis of the geo-scientific data and placing the well in favorable locale for the unconventional reservoir. This, coupled with the bold initiative of trajectory placement and proper completion of the well in Basement and Basal Clastics with MDT approach, helped in scripting this great success story.

The success of well-B and very recently of well-D could easily mark the beginning of focused development of the significant hydrocarbon resource known to be present in the deepest and unconventional reservoirs of Mumbai High.

## Authors' statement

Views expressed in the paper are those of authors only and not necessary of the version of ONGC. Further it is stated that data utilized will not affect ONGC's business interest.

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