



Challenges in identifying hydrocarbon potential in fractured Basement in Mumbai High field.

Uma Goyal *, S. N. Chitnis and B. B. Ray

Summary

Mumbai High field in the western offshore of India established the hydrocarbon accumulation in the Basement rocks through exploratory drilling way back as early 80's. The present study is an attempt to analyse the results of exploratory and development wells drilled to Basement and suggest way forward for optimization of exploration & exploitation strategy.

Though basement has been considered as an exploratory target for some time now, the inputs which such a complex target would deserve were rarely expended. So far, the efforts have been restricted to penetrating top part of Basement with basement being a secondary target, or just as sump for ensuring that entire sedimentary sequence above is logged. More over in most of the cases it has not been a target for special logs. Lack of advanced log data like FMI, DSI and CMR-ECS in the basement section is a constraint in fracture network analysis and characterization; as these studies form the backbone of hydrocarbon potential assessment for basement.

In order to improve confidence in basement exploration, iterative steps of using the existing data for optimal well placement and incorporating the data acquired through these new wells will be used in refining the existing model for better delineation of fracture basement targets.

Keywords: Mumbai Offshore, Basement Exploration

Introduction

Mumbai High field located in the western offshore of India established the hydrocarbon accumulations in the Basement rocks through drilling of exploratory wells. Mumbai High is India's premier multilayered oilfield. Fractured Basement, Basal Clastic, L-V, L-IV, L-III, S1 & L-I are the major reservoirs. The field is on commercial production of oil and gas since 1976 from L-III reservoir. Hydrocarbon was established in the Basal Clastic/Basement rocks in 1981. However, the focus remained on development of the multilayered prolific producing L-III reservoir. A few vertical development wells were drilled from platforms to Basement & Basal Clastic during the late eighties in different parts of the field. After over three decades of establishing hydrocarbon in Basal Clastic and Basement, an attempt was made to exploit oil from deeper unconventional Basal Clastic and Basement prospects in addition to the main L-III reservoir. Study area is indicated in location map of Western Offshore Basin as Fig. 1.

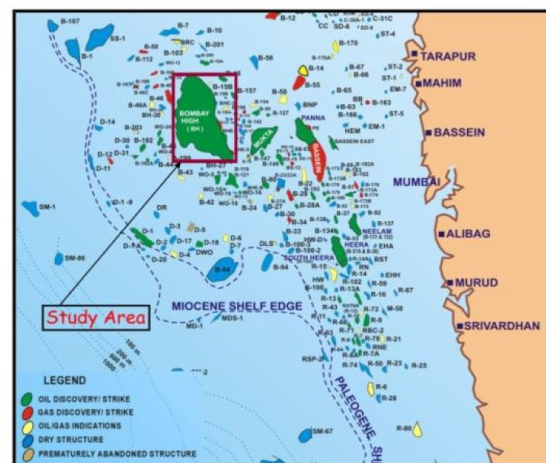


Fig. 1 : Location map

Basement is unconventional in the context of reservoir nature and, hence, complex to characterize and isolate the locales of interest. Hydrocarbon accumulations in Basement are generally seen in the fault zones and associated interconnected networks of fractures which account for the porosity and permeability.

Identifying and evaluating producing horizon is not the only challenge but drilling, suitable completion and stimulation too is a big task.

In this paper, we attempt to synthesize all the data available in the Mumbai High field on basement reservoirs with special focus on the drilling data, well testing data, basement composition, suitable completion and stimulation job that control their production in order to evolve a working strategy to realize the potential of basement oil exploration.

Regional Geology

The basic structure of Mumbai High is characterized by three major tectonic trends in the western part of the Indian shield: NE-SW Aravalli, ENE-WSW Satpura, and NNW-SSE Dharwar trends Fig.2. The field is giant paleohigh of the Precambrian granitic rocks overlain by Deccan Traps at some parts and clastics and carbonates over the greater part of the area.

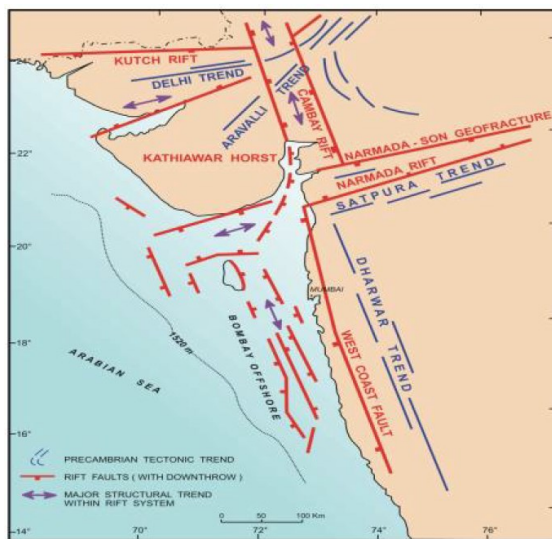


Fig. 2: Tectonic Trends of Western India

The Mumbai High East fault which acted as a fulcrum for all the tectonic activities in the areas witnessed is the single most prominent trend bounding the Mumbai high along its eastern boundary. It is a major zone of deformation comprising several faults which are offset by minor ENE-WSW cross faults. The eastern limit of the arch is a large-displacement fault which is about 60-70 Km in length and has throw ranging from 500 to 600m in the central part. The fault throw gradually reduces in magnitude in the north and south. The crest of the structure is intersected by

smaller faults which exhibit displacements of 50-60 m. Relief map on top of basement shows various tectonic elements of Mumbai High area Fig.3.

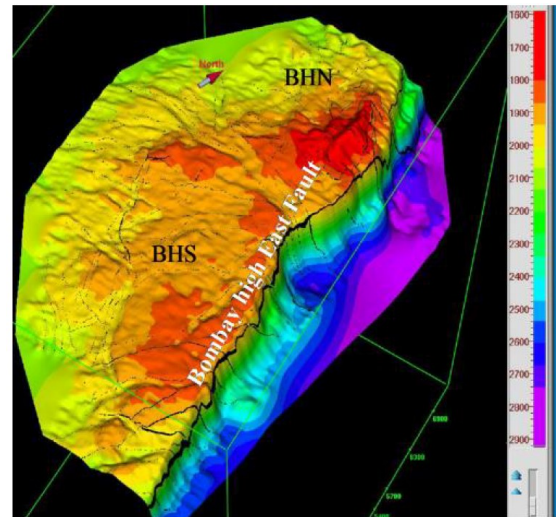


Fig. 3: Relief map of basement in Mumbai High showing major tectonic elements.(Source: MH)

The area along the main eastern boundary fault in Mumbai High field is a potential area for hydrocarbon prospect in fractured Archean Basement and Basal clastic sediments. The Mumbai High east fault imparts a different dimension to the porosities in basement by the way of high incipient stresses and renewal of these forces during various stages of reactivation of the fault. Some unusually high producing wells and surprising absence of the contributing layer in near vicinity suggest a possible steeply inclined disposition of the reservoir. This could be due to proximity to the Mumbai High east fault which is likely to have caused fracture zones around it. The Geo-scientific studies carried out by in-house and outside experts on Mumbai High field for field development and production improvement have indicated hydrocarbon potential in these reservoirs. The exploratory wells G, E and C drilled close to the main fault during 1987-1989 have produced oil ranging from 464 to 2575 bopd confirming hydrocarbon potential in basement Fig.4.

Thin clastics sequence forms the base for upper Tertiary sediments distributed mainly over the southern part of the field and overlying the predominately crystalline Basement. The Basement rock contains numerous fractures (a few mm to 0.5 cm width) of inclined nature in the nearby wells C and D Fig.4. The fractured Basement (sub-vertical fractures) and Basal clastics have been

proved to be potential pay zones with the production performance from few completed wells in the past.

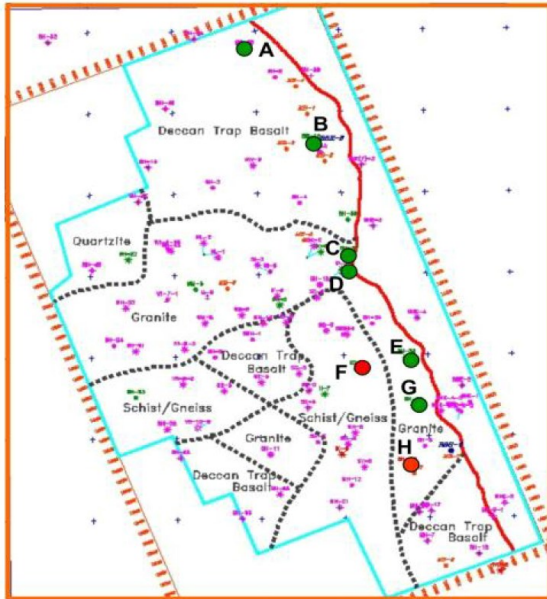


Fig. 4: Occurrence of oil & gas near the eastern boundary fault

Fracture analysis and Evaluation

Mumbai High field and the adjoining basement highs together are part of one of the most prolific hydrocarbon provinces of India. Given this fact, basement exploration effort in this area have remained restricted to exploring shallower basement accumulations, except a few wells which probed deeper part of basement, found mixed results. Basement rocks in Mumbai High area comprises of surrounding of composition ranging from Archaean Granite, Phyllite schist / Gneiss Quartzite and Deccan Basalt Fig.5. It is observed that the topography and fault pattern at Basement level is strongly influenced by the lithological composition. Granitic rocks which in general are more blocky and homogeneous are affected by fracture system which is long and interconnected as compared to the layered metamorphic rocks which tend to have disjointed fracture system. Periodic fluid migration along existing open fracture system, tend to seal major part of the fracture thus resulting in disjoint and reduction in void space as well as effective permeability. In the Mumbai high field it is seen that intensity of faulting is higher in the Granite as compared to the younger Basaltic flow.

In northern part of Mumbai High in Basaltic composition well-B interpretation of sonic log indicated that presence of fractured zone is developed 55m below the basement

top within the drilled section of 135 m. In southern part in granitic composition well-E, interpretation of PLT data indicated presence of six fracture zones 31 m below the basement top within the drilled section of 131 m.

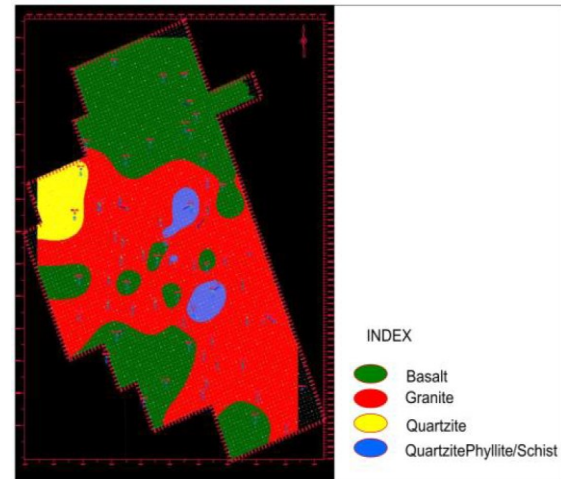


Fig.5: Lithology map of Mumbai High (Source:Geopic)

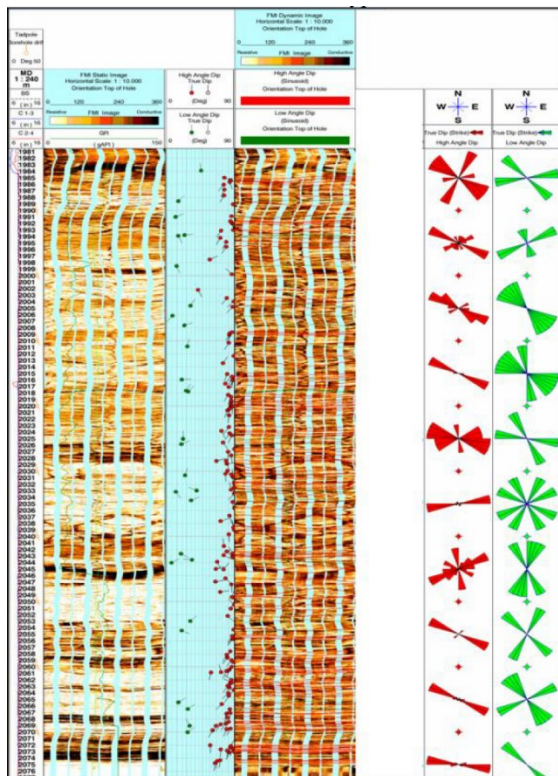
For better fractured basement reservoir evaluation, four elements are considered critical:

- Fracture class and density.
- Orientation (strike) and dip magnitude.
- Fracture aperture
- Fractured porosity.

Though fractures play important role for basement reservoir production but other factors like drawdown pressure, formation damage, maximum horizontal stress and fracture orientation degree of connectedness affects productivity.

Fracture evaluation by Core data

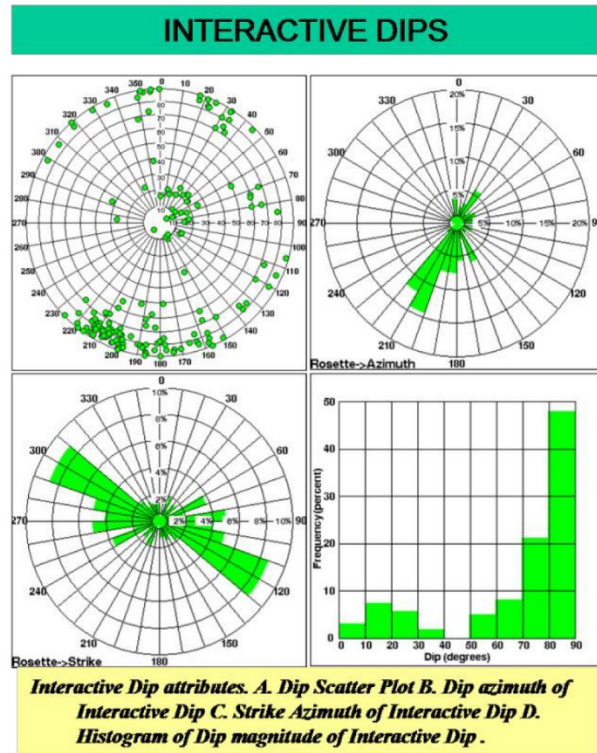
In southern part of Mumbai High field core were recovered in many wells located near eastern boundary fault and evaluation of cores indicated vertical to sub vertical fractures. Some of the fractures are high angle filled with oil and open/partly open in nature. In well-H estimated porosity from core varies from 5% to 20%. In the well-C, fractures in the core are observed to be filled with calcite, altered rock material (chlorite), secondary silica and some disseminated pyrite. Pyrite as dissemination is also observed on the surface of the rock type.



Depth wise variation in the strike azimuths of low angle and high angle dips

Fig. 6: Interpreted FMI image of well-A in Mumbai High shows the maximum principal stress direction at and around the well point oriented NNE-SSW; both low and high angle dips show strike azimuth as NW-SE

FMI logs recorded in two wells in Mumbai high which were drilled to basement has been analysed to decipher the principal stress directions Fig.6. The results analysed in well-A show lighter colored areas on the images are the areas of mineralization. Major feature on the images is the vertical fracture with strike NNE-SSW. The maximum principal stress direction is interpreted to be NNE-SSW around the well point. The dips analysis indicates that both high and low angle dips exhibits a common NW-SE strike direction. The High angle dips are mostly consistently dipping towards SW and the strike azimuth is NW-SE. Low angle dips are mostly dipping towards NE and the dominant strike azimuth is NW-SE. Low angle dips are probable fracture/fault plane dip. FMI log in well-D shows fracture orientations concentrated in NW-SE and ENE-WSW direction corresponding to the major orogenic trends which have affected the craton Fig.7. Log motif of basal clastics & basement section indicating near vertical fractures in well D and inclined fractures dip at an angle of 45° to 80°.



Interactive Dip attributes. A. Dip Scatter Plot B. Dip azimuth of Interactive Dip C. Strike Azimuth of Interactive Dip D. Histogram of Dip magnitude of Interactive Dip .

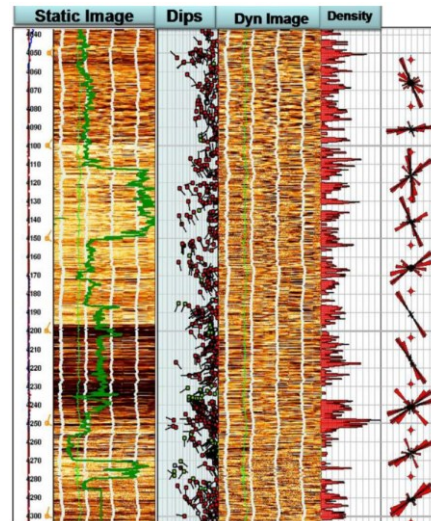


Fig. 7 : Interpreted FMI image of well-D in Mumbai High South showing fracture intensity to be the highest in conductive part (dark brown) and fractures oriented in NW-SE and ENE-WSW directions (Source : MH Asset)

Reservoir Architecture

The basement rocks at Mumbai high are tight and production relies on fractures, which are irregularly distributed and give significant variations in well productivities. More fractured zones identified along the maximum damage zone near the eastern boundary fault Fig.8. Well logging and PLT analyses show multiple fractured pay intervals. The average net reservoir thickness is 30 to 40 m. The intensity of fracturing in the basement tends to decrease with depth but increase in the vicinity of faults.



Fig. 8: Fault framework at the top of Basement- Mumbai High Field

Presently more than 700 wells completed in MH field, around 80 penetrated basal clastics and basement, covering length and breadth of the field. Out of 80 wells, nearly 50% of the wells were reasonably tested and reserves were established. Of the wells drilled upto basement, 50% of the wells penetrated less than 50 m of basement, 35% penetrated upto 100m and 15% wells penetrated more than 100m of basement section. As the well penetration was restricted to shallower part of basement, its true potential is yet to be assessed. Thirteen of the tested wells have been put on sustained production at different interval of time and have cumulatively produced 2.54 MMt of oil till Mar'2013, which is less than 2.4% of estimates. Most of the earlier wells are drilled as vertical but recently most of

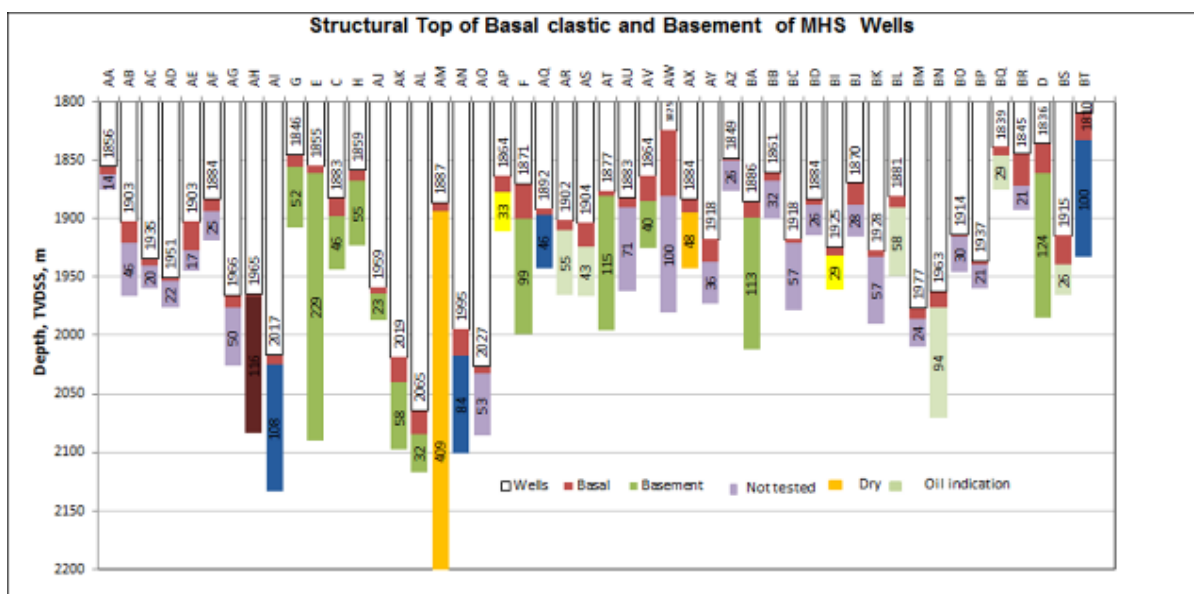
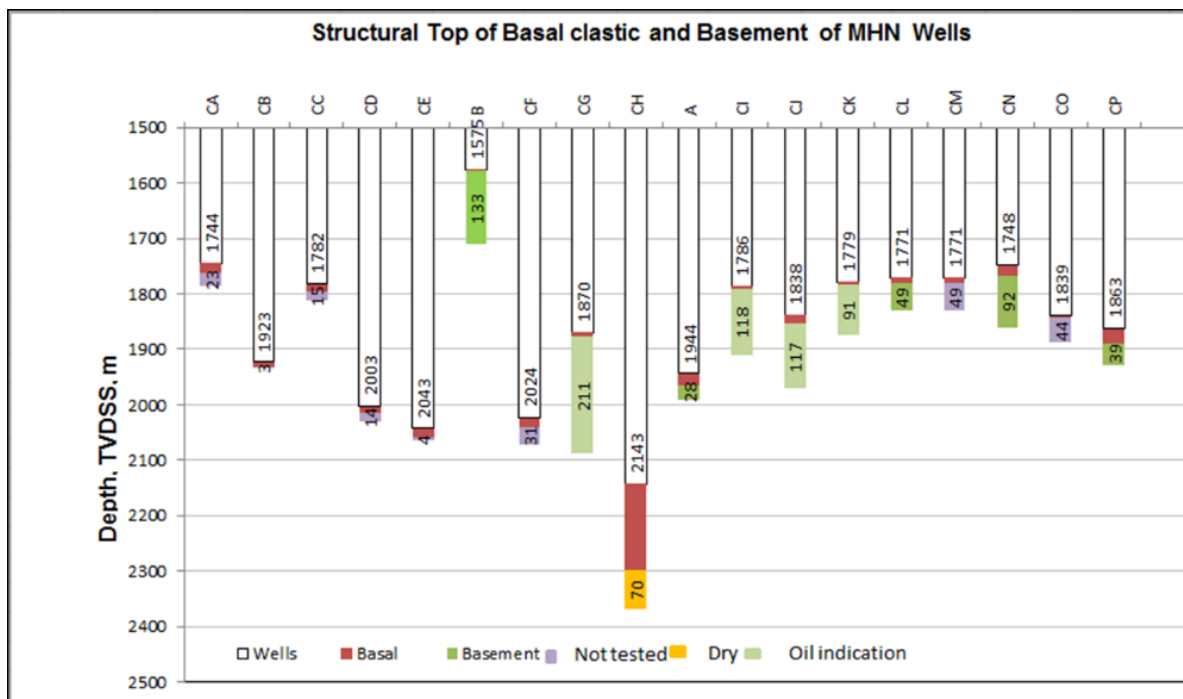
the wells have been drilled directionally (for more drainage area) upto 70°. These are producing with good oil rate. The wells have been completed with 6" hole with no liner though 8 1/2" hole would have been a better option. Recently drilled wells were drilled using water based/SOBM/Gel cement mud and loss prone L-III is isolated by 7" liner, lost circulation whilst drilling fractured basement is common. Most of the wells in basement reservoir are producing with gas lift but some are on self flow.

Production Characteristics

In fifty percent of wells drilled so far, the efforts have been restricted to penetrating top part of basement with basement being a secondary target, or just as sump for ensuring that entire sedimentary sequence above is logged. Earlier in most of the cases basement has not been a target for special logs but in last two year wells have been drilled with the objective to exploit oil from Basal clastic/Basement and special logs FMI and sonic log have also been recorded to understand the reservoir.

The Basal Clastics unit directly overlying basement in Mumbai high South, thought to be of Oligocene age, has proved to be hydrocarbon bearing in a number of wells. Except a few wells, all other wells in Mumbai high drilled to basement have been tested together in basement and Basal Clastics making it difficult to assess true potential of these discrete units. First attempt to bring out a geological model on Basal Clastics on Mumbai High was made in 2010-11 and locations were drilled based on the model with mixed success.

Overlying prolific producing reservoir L-III and other HC bearing horizons L-V & L-VI are encountered in the upper sections. Due to production from upper prolific L-III layers, the pore pressures of these reservoirs have dropped substantially. Thus, there is a situation where a sub hydrostatic layer is in between normal pressured shales and underlain by normal pressured limestones L-V & L-VI causing the problem in drilling the wells for basal clastic/basement.



The basal clastic/basement reservoir was put on production in Aug'81 with oil rate of 1132 bopd with no water cut through well-I. Present production from Basal clastic/Basement is over 3700 bopd with water cut nearing 50% and GOR of about 340v/v through 6 wells.

The completion of wells in basement is a great challenge faced the problems of suboptimal casing/liner size for completion, and difficulty in separating contribution from Basal clastics (these being hydrodynamically continuous units) and Basement which is essential for assessment of true potential. Inputs on suitable completion design for optimal production from these units, either in cased hole or



open hole scenarios, where proper estimation of potential of these units, is constrained due to comingle testing, without isolation between contributing layers.

Six wells have been drilled and completed in Basal clastic/Basement during the last 2 years. These wells showed mixed results, two wells are producing around 1200-1500 bopd with 18-30% water cut while others are average producers. Two wells are low producer though the logs of the wells suggested presence of hydrocarbon in Basal clastic/Basement.

Challenges

1. Significant reserves and limited production.
2. Comingled production with Basal Clastics makes it difficult to assess true potential.
3. Deeper Basement section poses drilling challenges.
4. Mapping of basement fractures through seismic, FMI logs and core data.
5. Fracture network characterization with connectivity analysis, identification of optimum drainage points, flow pathways, reservoir compartments and volume estimation.
6. Reserve estimation for Basement.
7. Achieving optimal hole size.
8. Conventional coring and sidewall coring.
9. Heterogeneity and complexity of fluid-flow paths in fractured rocks.

Best Practices

Based on the analysis of the Mumbai high data the following key observations are made:

1. Recognize basement reservoirs as more complicated than conventional ones. It requires specialized 3D seismic survey/re processing.
2. Coring & special logs for identification of fractures to get a better control on reservoir characterization.
3. Geomechanical modeling and stress analysis.
4. Drill at high angles near perpendicular to the fractures with sufficient penetration in basement.
5. Prolonged production testing, intelligent completion with use of ICD/ICV technology for control of water production.
6. Installation of down hole pressure gauges for continuous pressure recording.

7. Record PLT to test individual fracture zones dynamically for comparison with log measurement.

Way Forward

Basement hydrocarbon exploration efforts offer opportunities to unlock significant resource in various Petroleum provinces of India. Many of the areas where basement is being initially focused already have the surface facility for exploitation. In the western offshore area, a number of development wells have been drilled in basal clastic/basement and some of which can be re entered for initial probing thus reducing the risk to a certain extent. The challenges exist right at the exploratory stage, where the existing seismic data has been acquired and processed with focus on sediments above the basement. The azimuthal parameters and low frequency seismic data in the process has not been captured for basement. State of the art seismic data acquisition and processing techniques like 3D-4C, Broadband technology, Controlled Beam Migration can be tested to ascertain their true potential. Reprocessing of existing 3D seismic data is a possible quick move initiative; however this is constrained by inherent quality, and acquisition parameters. This 3D seismic data can be reprocessed with specific filters and minimum amplitude distortion to bring out the horizon and volumetric attributes of basement intervals for the static model. Multi component VSPs and borehole acoustic and other imaging data FMI, DSI along with MDT (straddle packer) samples and oriented cores will help refine the static model.

Drilling high angle inclined wells into basement prospects with underbalanced mud is the practice worldwide, as it improves the probability of penetrating more number of fractures. Given the production history and pressure depletion profile of overlying sediments in some areas, drilling to basement with a desirable hole size, would need innovations in well design and application of latest drilling technologies. The advantages of managed pressure drilling of basement prospects are yet to be established. For reservoir evaluation and preparation of dynamic model, conclusive production testing, PLT data in conjunction with DSTs and pressure transient analysis may help mitigate the risks of developing YTDs in such types of unconventional reservoirs. Well stimulation designs have to be designed keeping in mind the geological history of the region.



Conclusions

Basement hydrocarbon exploration and exploitation depends on various factors like, advancement in seismic imaging technologies which offer better imaging solutions, advances in drilling technologies, better drilling fluids, smart completion and techno-economics have made look for unconventional reservoir.

1. Identification of faults and fractures zones using coherence cube techniques by carefully matching well data with reprocessed 3D seismic, as high levels of deformation associated with fault propagation tend to induce higher fracture density. Proximity to major fault zones is one of the key consideration for better reservoir quality.
2. Basement composition plays an important role, as different rocks, have varying elastic properties thus creating variable magnitudes of fractures.
3. Directional wells drilled perpendicular to the direction of maximum horizontal geostress and deeper penetrating sections where there is evidence of both faulting and fracturing on the seismic, have proven to be the best candidates for good oil production.
4. The close integration of both the electrical image and stoneley acoustic waveform data has further help to identifying & evaluating producing horizons in fractures basement
5. Further in order to exploit the full potential of basement reservoirs, drilling of high-tech wells and completion needs to be state of art technologies to further explore and optimally exploit unconventional reservoirs. It needs to acquire necessary state of art drilling tools to drill deep into Basement approximately 300 m or more.

As more wells are drilled, it has become possible to better correlate and map the producing horizons. This clearly allows better planning of the location of future wells, and the thickness of the reservoir section which needs to be penetrated, so optimizing field economics.

Acknowledgements

The Authors express their gratitude to ONGC for permitting publication of this paper. The Authors also express their sincere gratitude to Shri. N.K.Verma, Director (E), for extending encouragement at every stage.

The support and advice by Shri.P.K. Bhowmick, ED COED, WOB is gratefully acknowledged. The technical support and knowledge inputs provided by geoscientific team of WOB and MH-Asset are thankfully recorded. The authors also extend gratitude to all fellow colleagues of CoD Basement Exploration, for their support and assistance.

References

- Agarwal,G.C et al (2007) Hydrocarbon potential of Basement rocks of Western Offshore Basin (Mumbai high & Heera) : published report by ONGC.
- Nauriyal A K et al (2010) Identification of discontinuities by attribute analysis and planning of well for basement exploitation-A case study in Mumbai High Field.
- Satyanarayana, P. et al (2008) Fracture characterization on Basement reservoir, a study on Mumbai High: Geo India 2008.
- Sinha, P.K et al (2011) Assessment of HC potential of Sub-L-III layers (L-IV, L-V, L-VI & Basal Clastics) and Basement reservoirs of Mumbai High field : published report by ONGC.
- Vasudevan K. et al (2009) Role of Regional Tectonics and Fracture orientation: Technical Synopsis & Potential of Indian Basins, a Term Paper.