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Characterizing and exploiting Indian Basement plays: no quick fix.

Abstract

There's an old adage in the oil industry first coined by Parke A. Dickey in 1958 that…"*We usually find oil in a new place with old ideas. Sometimes we find oil in an old place with a new idea, but seldom do we find much oil in an old place with an old idea. Several times in the past we thought we were running out of oil, when actually we were running out of ideas*". Understanding the basement architecture, basins evolution and their tectonic framework is a dynamic process. Integration of new set of data coupled with regional concepts have redefined the exploration frontiers for basement hydrocarbon resources in India, which are more complex and challenging than what was conceived yesterday. Perspective plan 2030 of ONGC envisaged equal importance to be accorded to resource generation through establishment of *yet to find* reserves in basement and simultaneous conversion of these reserves to producible resources for quick economic gain. Advanced fracture characterization tools, refined drilling and fracture stimulation techniques coupled with fast track resource conversion, have delivered encouraging results in the Indian basement E&P portfolio, barely imagined before.

Introduction

Current exploration trends will follow the industry's perception of the "next best resource base" to explore and develop, which incorporates both the scale and quality of resource and the cost of its development. Basement exploration in Indian sub basins vis-à-vis global trends influencing exploration hinges on two key points – future resource trends in terms of huge unexplored rock volume in basement, and future technology trend in terms of striving for the perfect seismic image and transformation of reserves to resource. The first point involves evolution of an optimistic workflow involving regional to point scale data integration and the second point is the economic key indicator of future exploratory and development efforts in Indian sub basins.

Going back to first-principals, interpretation of basement terranes and major structures across the basins, provided a spatially consistent and continuous view of the geological fabric. Working back in time to undo deformation patterns on major lineaments and shear zones affecting basin architecture helped provide a kinematically and geologically constrained gross view of the tectonic evolution of basins. It is consistent with the evolution of basins and petroleum systems across the basins, and has been used as a predictive tool for basement exploration. The Indian basement experience, particularly in the development journey in Padra, Madanam, Pandanallur and Pundi fields, has shown that it requires a combination of high resolution seismic, geological and fracture related reservoir engineering, log data analysis and geo-mechanical understanding.

The immediate challenges faced in basement exploration and exploitation in the Indian sub-basins are: a) accessing azimuthal information from seismic data and reliability of same in deeper realms, b) basement depth imaging and mapping, c) identification, mapping and understanding of source rocks and petroleum system feeding the basement, d) reservoir characterization highlighting basement anisotropy, and e) achieving the technical competence to find and produce basement oil. Definite actions envisaged for Basement characterization in the medium to long term action plans are identification of target areas for basement exploration based on comprehensive fracture model, drilling sufficiently deep into the basement guided by source proximity and thickness, extensive wireline log coverage for understanding the fracture system and extended testing of the fractured basement rock to realize actual potential.

Characterizing Indian basement resources

Regional analysis of Indian basement reservoirs reveal that elements of basement structural grain often propagate upward from crystalline basement through the sedimentary section to the surface and often controls the edges of basement oil reservoirs in subtle ways. One of the most effective ways of understanding the big picture of basement control is to look at the structural grain interpreted from regional lineament mapping, High Resolution Aero-Magnetic and gravity data and compare with well data and geological mapping. A broad understanding of the nature of Indian basement reservoirs arrived at by integrating regional studies with available well data and historical data from world basement reservoirs has been achieved as a primary step to carry forward basement exploration on a fast track (Table 1).

Table1:

Basin	Assam Arakan	Cambay	Western Offshore	Krishna Godavari	Cauvery
Tectonics	Extensional / Wrenching	Extensional	Extensional	Extensional	Extensional/ Wrenching
Structural style	Buried hill	Basin Margin Fault closure	Intra basinal high / Paleo high	Intra basinal high	Intra basinal high ; Basin margin fault closure
Fracture Mechanism	Reticulate, extensional faulting due to vertical bsmt.uplift & wrenching	Extensional faulting, sub-unconformity weathering	Extensional faulting / Bmt uplift & weathering	Extensional faulting (Eastern ghat trend)superimposed by NW-SE rift trend	Extensional / Wrench faulting
Trapping Mechanism	Domal / faulted anticline due to Bmt uplift; faulting and weathering	Combination Faulting & weathering	Combination Faulting & weathering	Horst blocks / Basin margin faults	Structure related to horst faulting; shear zone induced brecciation
Reservoir Type	Type II	Type II	Type I and II	Type II	Type I and II
World analogues	La Paz-Mara Field, Venezuela :	Wangzhuang field, China	Bach Ho Field, SE Vietnam	-	Dongshengpu field, NE China

The focus on characterization of basement reservoirs in Cauvery basin has gained prime attention after commencement of production from basement reservoirs in Madanam, Pandanallur and Pundi areas. The uplifts or buried hills, that form the basement reservoir, are simple basement highs (or hills), upthrown sides of faulted blocks, horsts, or basement highs within a graben. The E-W shear trends are the most reactivated trends under the present day strike slip stress regime prevailing in Cauvery basement fields. Fracture sets oriented in NW-SE and E-W direction are more prone to being critically stressed and are likely to remain open (Kumar,S.et al, 2017). This trend is the most important trend instrumental in migration, remigration or non-migration of hydrocarbons and hence has significant bearing in heterogeneity observed in flow potential of basement reservoirs across different fields (Mukherjee, S.K. et al, 2017). Detailed analyses of image and shear logs and production performance of basement wells in Pundi, Mattur, Pandanallur and Madanam fields support the findings. Geomatic studies indicate that areas of intersection of post Pre-Cambrian faults overlying older Pre-Cambrian shear zones are areas where maximum fracture intensity is observed (Mazumder, S. et al., 2015). Basin modelling studies (KDMIPE, 2015) have indicated significant lateral migration loss in Cauvery GME model. Hence presence of suitable intensely fractured basement (first available structures) in proximity to source pods with strong up dip seal classify as primary targets.

Basement exploration in Krishna Godavari basin is still in nascent stage though the critical elements relevant to basement prospectivity exist in this basin. Prospective areas for basement exploration in this basin are the NE-SW trending Tanuku Horst between West and East Godavari sub-basins and Poduru-Yanam-Draksharama-Endamuru High in East Godavari sub-basin where the prominent horsts are bounded by Chintalapudi and Pithapuram cross trends with the Kommugudem Formation (thick and matured source facies of Permian age) directly juxtaposed against the basement high. Another prospective area is the NE-SW trending Kaza-Kaikalur High in West Godavari sub-basin which lies between Chintalapudi and Avanigadda cross trends. In Gudivada graben the horst is directly

juxtaposed to the proven source kitchen that is Gajulapadu shale while in Bantumilli graben the Kaza-Kaikalur horst is either overlain by or juxtaposed to the Raghavapuram Shale. Regional stress analysis envisages that the NE-SW trending faults and NNW-SSE oriented fractured sets are likely to have good dilation potential and are conducive to fluid flow. Fault zones and fault tips at Kaikalur high, north of Bantumili high, Tanaku high, Draksarama high and Yanam high can be the logical targets.
Basement exploration in neo-tectonically active areas of Upper Assam shelf south, close to Naga thrust, is besot with intense technological challenges right from seismic imaging, static modeling, optimizing well paths for development locations, well stimulation and completion designs. E-W trending discontinuities/ faults and also the NW-SE grain remain the most reactivated trend in the basin and fracture sets oriented in these directions have high dilation tendency in present day stress regime. Basement reservoirs are of Type-II with significant contribution from weathered/brecciated basement (matrix porosity) supported by fracture permeability. Fracture modeling of Borholla field, a known basement producer, have demonstarted that maximum fracture intensity is encountered in the flanks of the antiformal culminations. It is validated by wells drilled on the flanks which have produced with low GOR and negligible pressure reduction operated by active bottom water drive. The undrained volumes of Borholla area can be best exploited through high angle or horizontal wells in NNW-SSE directions as fractures are oriented NW-SE and E-W . Preliminary analysis of basement prospectivity in Upper assam shelf, north reveals that basement highs when associated with reactivated faults, delineated to be acting as conduits, might serve as areas of exploratory interest in the area. Analogue modelling and gross fracture characterization studies suggest favourable basement prospectivity perception along basement ridges existing all along the frontal belt from Geleki to Khoraghat structures. These areas which may be analysed for re-entrants in the foreland areas and areas close to Jorhat fault on the upthrown side are promising from hydrocarbon point of view in basement.

Mumbai High field and the adjoining basement highs in western offshore are part of one of the most prolific hydrocarbon provinces of India. Recently gas discoveries in Deccan Trap in Kutch block have evinced keen interest in evaluating Trap in terms of hydrocarbon potential. Out of an estimated resource base of 450 MMt in basement, only 12% conversion to reserves has been possible, which itself is an indication of huge YTF resources still to be established in this basin. The most significant commercial discoveries have been reported in Mumbai high and its extension southwards, B-119/121 structure and Heera which have a milieu of metamorphic and basaltic basement. Common observations from seismic fracture attributes and intensity models (based on petro-physical parameters as well as incremental strain analysis) suggest basement prospectivity around fault damage zones, fault tip propagation fractures, at junction of significant tectonic cross trends and step and jog zones. Common observation from recently drilled wells in Mumbai High is the tendency for fracture height and dimension to be limited in metamorphic formations by the layering and denser fracture clustering in more felsic bands. Discovery of oil and gas at same structural level (or gas in shallower levels of basement) in Mumbai high points to the role played by genetic and kinematic relationship of fractures with fault reactivation vis-à-vis accumulation in basement. 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. Similar tectonic set up in Heera makes targets close to Heera east fault logical for basement exploration. Other than areas where basement highs or fault cross trends are prominent in Western offshore, proximity/ juxtaposition to source is another factor which makes areas adjoining central graben and the eastern homocline attractive in and around structures like B-23A, B-28,B-147 and B-182. In North Tapti area, the reactivated faults played a big role in the migration and accumulation of hydrocarbons and have a direct bearing on fracture orientations which have distinct imprints of Riedel shear. Fracture characterization of Trap reservoirs in GK-28 and 42 structures in Kutch offshore have demonstrated that the most porous reservoir part is in the top weathered / moderately altered Trap portion. Lateral extent of this reservoir is vast as all the well logs exhibit the top part of trap to have the necessary properties required to qualify as reservoir provided the top seal is not breached.

The fracture genesis in Cambay basin Trap cover is closely related to its extensional architecture defined by two types of faults: the listric-normal faults striking N-S to NNW-SSE and the transfer faults, trending ENE-WSW to NE-SW. Transfer faults frequently offset the listric faults and also the rift border faults. Basaltic basement reservoirs as in Padra-Karjan area are moderately altered basalts with preserved igneous texture. These have effective permeability and porosity to host hydrocarbon. The overlying clays, part of which are alteration products of basalts, or relatively unaltered basalt form the cap rocks. Although weathered zones within trap and volcaniclastic/ intertrappean beds are important from exploration point of view, but prediction of such features is a real challenge. Long distance migration from source to basement and effect of meteoric waters can lead to biodegradation and result in heavy oils as found in Charada and Mansa areas on the eastern margins. First available updip structural/ fault closures close to path of migration (cross faults/ transfer faults) and near to source are the best available areas for Trap exploration in the eastern margin of Cambay basin.

Following key understandings emerge from basement characterization in Indian basins.

- Basement accumulations are primarily result of short distance migration influenced by faults and unconformities making first available structures proximal to source the primary targets.
- Neo-tectonism has profound effect on fracture dilatancy and fluid flow potential.
- Fractures occur in clusters influenced by lithology, rheology of the rock and tectonics.
- Hydrocarbon accumulations exist beyond 200m within basement and are exploitable.
- Reservoir compartmentalization is common phenomena within basement

Strategizing on economic and technology leverages

Having understood the gross uncertainties and risks involved, future of basement exploration in India will depend on geopolitics and fiscal regimes. Under the current oil price regimes, keeping in mind the crude price volatility, the oil and gas exploration industry has a clear way forward: less is more (Latham, Andrew Dr., 2017). Tight budgets and relentless effort will reduce cost across exploration and development. The latter will be key to improving resource conversion of discoveries and recovering a part of the exploration costs. Worldwide statistics and Indian experience suggests that basement drilling and completion activity is a high cost activity with an inherently low overall success rate of striking commercial hydrocarbon. This low probability of success occurs despite the significant level of “science” that is brought to bear by industry, and illustrates the complexity of factors, in this case fracture anisotropy, that must align for volumes of hydrocarbons to accumulate and be discovered. Key to understanding this complexity is historic well data where big data analytics can be efficiently utilized to highlight the opportunities.

Basement reserves in Indian sub basins are often small reserves locked in culminations which may not be economically feasible to develop independently. Strategy to prepare combined development plan for all the upside pools along with basement make it economically viable as seen in fields like Padra and Pundi. Many of the areas where basement is being initially focussed already have the surface infrastructure in place. In the Western offshore area, re-entry through sick or non-performing development wells or utilising empty platform slots for initial basement probing can reduce the risk to a certain extent. The exploratory well BH-X in Mumbai high could be successfully steered from vacant platform slot in the desired azimuth to achieve desired results (Figure 1).

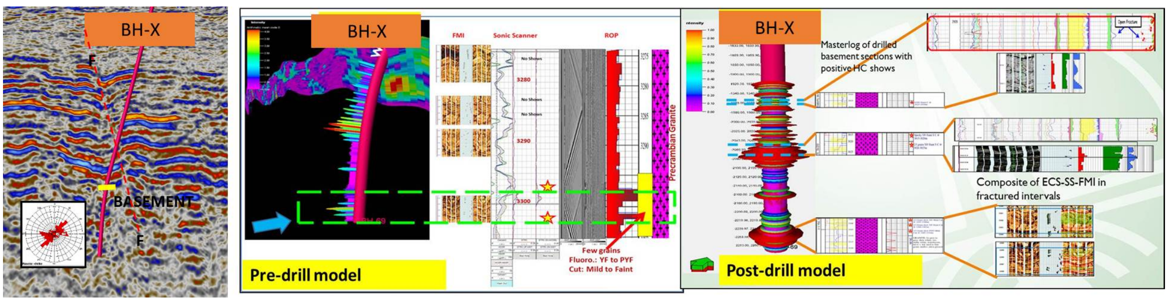

Figure 1: Integrated basement characterization in well BH-X showing optimised well path

In order to capture the azimuthal parameters and low frequency data for characterizing basement discontinuities, recent seismic data acquisition like 3D-3C, Broadband technology, and processing techniques like ES 360 and Controlled Beam Migration can be tested to ascertain their true potential. Reprocessing of existing 3D seismic data is a possible quick move initiative, though constrained by the 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 along with MDT (straddle packer) samples and oriented cores will help refine the static model.

Drilling high inclined wells into basement with underbalanced mud or non-damaging drilling fluids is the practice worldwide, as it improves the probability of penetrating more number of fractures. Determining trajectory and well inclination in basement intervals is dependent on stress regime prevailing in the field. The advantages of managed pressure drilling of basement prospects and exploiting basement resources through multilaterals are yet to be established.

In Indian basins, poor well test results in old wells where basement testing was not accorded the time and technology to prove itself, led to negative assumptions even if they have not been subjected to rigorous post well analysis. A holistic approach to basement exploration that incorporates technical results, an improved understanding of the petroleum system, fracture anisotropy model and the best completion techniques can help increase the chance of success as seen in recently drilled wells.

A recent well, Heera-A, was side tracked from a platform well in an identified permeability sweet pod to test the integrated fracture model which had been developed integrating fracture intensity model, genetic model, geo-mechanical concepts, and information from flow data. Data collation from Litho-scanner log, FMI and UBI log, and Sonic scanner anisotropy data led to the identification of NW-SE oriented critically stressed fracture swarms in the top 70m of basement where minor hydrocarbon shows were observed during drilling (Figure 2). These critically stressed fracture zones were correlated with Litho-scanner derived fluid interpretation to gain an idea of the fluid content of the reservoir and its potential to flow. Intervals with significant near wellbore damage seen by the Sonic scanner were perforated in open hole and the well flowed hydrocarbons.

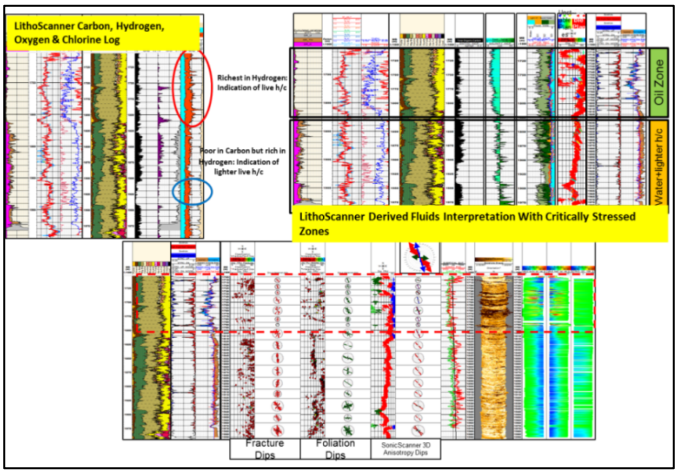

Figure 2 : Integrated petro-physical fracture characterization in Heera-A

Parameter fixation for basement reservoirs requires improved synergy between the static and the dynamic models, as basement reservoirs are more complex as compared to conventional layers. For preparation of dynamic model, conclusive production testing, PLT data in conjunction with drill stem test (DST) results, and pressure transient analysis may help mitigate the risks involved in reservoir evaluation. Water loading in basement wells, which is a common phenomenon, can be controlled through water shut off jobs designed on well case basis. Recent successes in shutting off water contributing fractures in Dayalpur (Figure 3) and Babejia fields in Upper Assam shelf, utilising knowledge of fracture distribution pattern and PLT data have yielded positive results in terms of increased hydrocarbon production. Challenges of producing heavy oil from basement reservoirs is still in the pilot stage and requires more thrust to bring in advanced technology. Selective isolation of basement fracture clusters for initial testing, as attempted in a Mumbai high basement well recently, is a bold step towards realising true potential of basement, but requires more technological inputs.

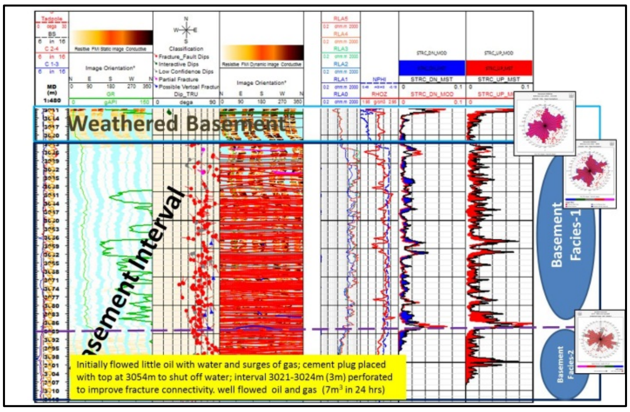

Figure 3 : Fracture characterization for successful water shut off job in a basement well in Dayalpur

Basement reservoirs in general are characterized by poor intrinsic permeability and need suitable IOR techniques for increased recovery. The White Tiger experience in Vietnam has shown that suitably designed IOR techniques including advanced emulsion acidizing stimulation, microbial enhanced recovery methods, proppant hydraulic fracturing and gel treatment for basement have almost doubled the recovery factor.

The road ahead

In the Indian context, most relevant would be to define basement reservoirs as *exploration play* instead of a *proven play,* which will help us to manage the risks inherent in new and existing venture evaluation (Doust, H. 2009) as well as in development ventures. The play concept will help in

- identifying where and to what objective future exploration activity should be directed,
- management of the risks associated with drilling basement prospects,
- prediction of possible volumes using successful analogue fields or statistical techniques,
- identification of the technologies needed to maximize the commerciality of discoveries,
- deciding when an exploration venture in basement should be terminated based on the perceived risks and actual drilling results.

Each development objective in basement is to be treated at par with an *exploration play* and all relevant physical data acquired for reservoir characterization so as to constantly upgrade existing fracture model for better exploitation of the reservoir, as is in practice in Madanam field of Cauvery. Integrated static 3D fracture model calibrated with actual well data helps predict fracture networking with good confidence and provide real time solution to completion planning of wells in basement.

Historically, continuously improving and developing drilling and completion technologies is one of the effective ways to solve the high cost problem in exploration and exploitation of basement hydrocarbon resources in volatile oil price regimes. The way forward for basement exploration in Indian sub basins will require more creativity in identifying prospects, method innovation in characterising promising prospects, and more integration and extensive use of technology to convert the prognosticated resources to energy resources. Under the present economic scenario, joint exploration and development of basement reservoirs in Indian sub basins has the potential of meeting the current requirement of resources, technology, risk mitigation through positive economics, and addressing land availability issues. This will help realise comprehensive utilisation of resources and has the feasibility of implementation on a fast track.

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References

Doust,H.,2010,The Exploration Play - What Do We Mean by It?,Search and Discovery Article #40486.

Integrated Geological modeling of Cauvery Basin including Petroleum System(s) Modeling, KDMIPE, ONGC unpublished report, September 2015.

Kumar, Sushil, Baruah, M.K. and Bhalla, A., 2017 Fracture Network modeling and Tectonic History of Basement Rocks of LI and LII PML Area of Cauvery Basin for Hydrocarbon Prospectivity analysis., KDMIPE, ONGC unpublished report.

Latham,A.,Dr.,2017,How Exploration Will Fix Its Broken Economics,SEAPEX Exploration Conference.

Mazumder, S., Blecy Tep and Pangtey, K.K.S., 2015, A Remote Sensing and GIS based integrated approach for identifying promising areas for Basement exploration in Cauvery basin,11th Biennial International Conference & Exposition, SPG India.

Mukherjee, S.K. and Chitnis, S.N., 2017, Addressing Granitic Basement Reservoir Heterogeneity in Cauvery Basin: an Integrated Fracture Modelling Approach, AAPG GTW, Mumbai, India.

Ray, B.B, Chitnis S.N, Mukherjee S.K, 2013, Exploration for Hydrocarbons in Basement: Mumbai to Borholla to Madanam, SPEB 3, January 2013.