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Hydrocarbon prospectivity in Basement in South of Mumbai High: an integrated model based approach

Abstract

With known hydrocarbon accumulation in basement, Mumbai High field and its adjoining areas in Western offshore, India is a priority area for extending the concept of fracture characterisation in metamorphic and basaltic basement reservoirs. Basement in Mumbai High is established to be hydrocarbon bearing in areas proximal to major fault damage zones and intersections of major regional tectonic cross trends. Recent discoveries in South of Mumbai High which has similar tectonic and structural setup have necessitated fast tracking of fracture characterisation in this area. Major challenge lies in determining the vertical and lateral variations present in the area by characterising the role of faults and fractures using point scale well data and taking into account the lithological considerations. Secondary porosity development in the reservoir is limited to weathering and fracture density developed due to tectonic and diagenetic processes. Fracture modeling workflow has been adopted to characterise the fractured basement in the South of Mumbai High area. The static model with integration of seismic, petrophysical, geomechanical and geological data satisfactorily explains the anomalous hydrocarbon accumulation and flow behaviour of the basement wells tested in the area. The workflow has proved to be of immense help in planning exploratory wells as well as exploiting accreted reserves in basement.

Introduction

Hydrocarbon occurrence in basement has been established long back in areas near Mumbai High East fault which defines the eastern limit of the giant Mumbai High field. Subsequent to these, few wells were drilled in the Mumbai High and B-119-121 structures. These discoveries have led to focussed attention on geologically similar areas, north of B-119-121 structure which already had indicated presence of oil and gas from basement. The area is extensively affected by tectonic disturbances giving rise to fault tip propagation fractures, and lies adjacent to the main source rich low to the east.

In the current study, area lying south of Mumbai High, and to the north of B-119-121 field has been focussed. The entire area extending from Mumbai high to B-119-121 structure with the South of Mumbai High (SMH) basement promontories in between are affected by three dominant tectonic trends, viz., NNW-SSE, NE-SW and ENE-WNW which have controlled the fracture genesis in the area. Fractured granite gneisses and basalt are known to host hydrocarbons in this area. Anisotropy in basement in this entire corridor has been induced by tectonic disturbances and shallow diagenetic effects which have provided porosity and permeability to these reservoirs. Diagenetic processes have formed a thin veneer of weathered basement overlying fractured basement. Panna Formation provides the main source facies.

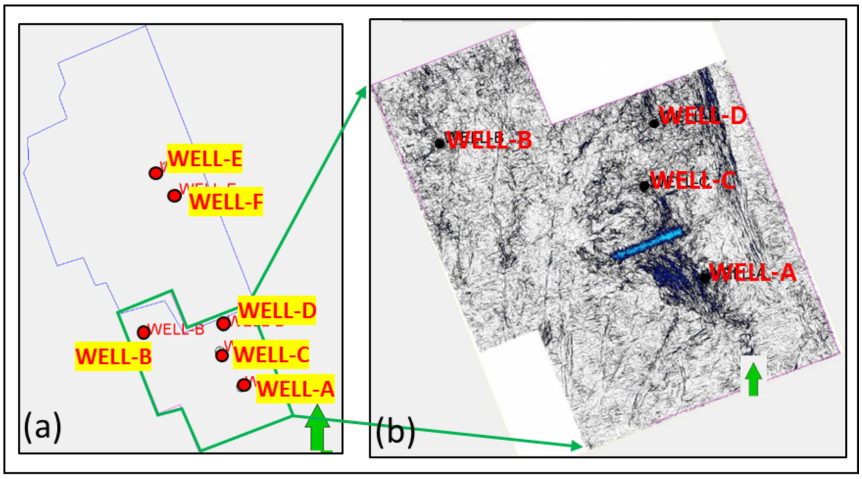

Fig 1: (a) Base map with key wells; (b) AntTrack™ depth slice near basement top in South of Mumbai High area

Orientation of DITFs was analysed to deduce the present day stress orientation from the FMI™ (Formation Micro Imager) logs of the key wells. SH_{max} is oriented WNW-ESE (parallel to the Mumbai High east fault) as deduced from the DITFs which is in agreement with regional stress map indicating NW-SE direction (Mukherjee S.K. et al, 2016) (Fig 2).

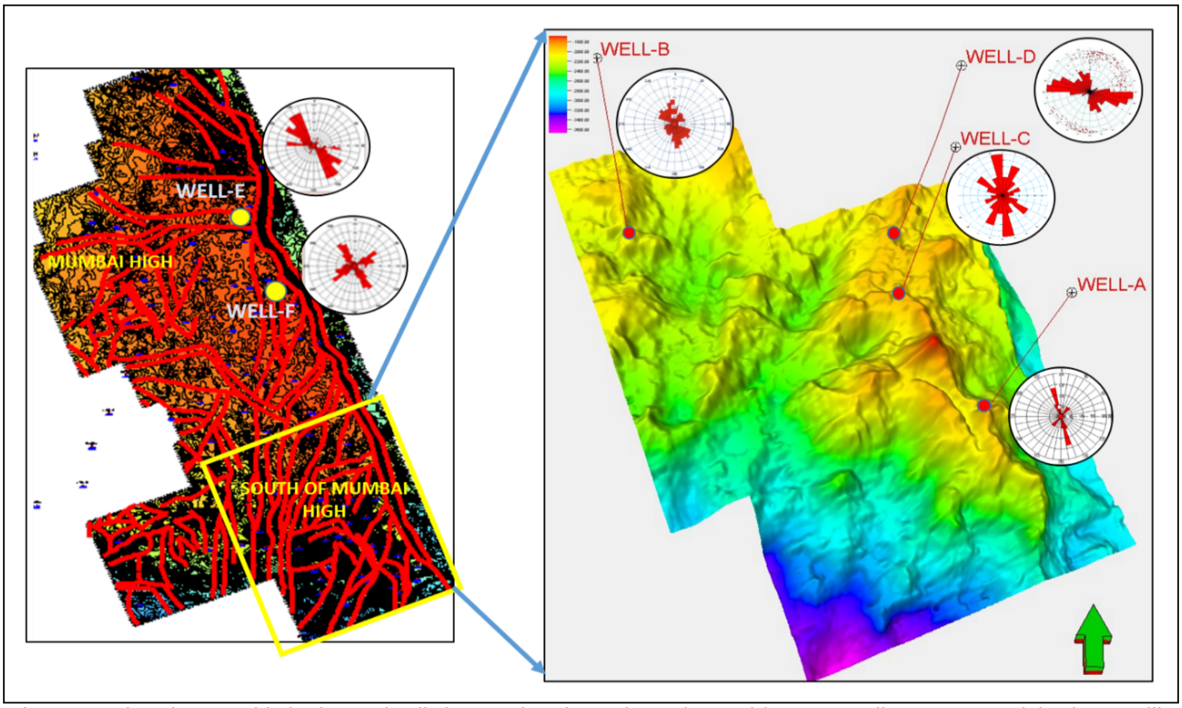

Fig 2: Regional map with faults and relief map showing orientations of fracture strike rosettes of the key wellls

In order to extend the point scale information derived from the well logs to field scale, analysis of role of faults and fractures along with the lithological considerations is essential. It is thus mandatory to integrate seismic, petrophysical, geomechanical and geological data to arrive at a robust fracture intensity model. In the present study the model generated was calibrated with existing wells and a reasonably good match was observed. Two wells drilled on the basis of such analysis proved to be hydrocarbon bearing in basement.

Methodology

Understanding the fracture properties like fracture openness, porosity (primary and secondary), permeability, etc. is important to analyse the quality of a basement reservoir. Along with these, their orientation, density and aperture also play a major role as they determine the possibilities of hydrocarbon migration from source to reservoir at the time of migration as well as entrapment in fractured reservoirs. Tectonics holds its own share in determining the various stresses acting upon an area. The orientation of Drilling Induced Tensile Fractures (DITFs) and borehole breakouts observed from the resistivity image logs corroborate with the stresses acting at present and thus guides towards understanding the present status of fractures.

The point scale data used for fracture characterisation included the basic logs, i.e., resistivity, density and sonic logs aided by the resistivity image logs which helped in deciphering the fracture attributes as well as the stress orientations.

Open hole logs along with resistivity image logs and stoneley waveform analysis logs were analysed to mark the fracture intervals present in the basement section. Open hole logs suggest presence of possible fracture zones from the anomalies observed in resistivity and neutron- density log. These fracture intervals when compared with the fracture dip intervals from resistivity images logs give a fair idea on the conductive and resistive zones present in the section. Open fracture intervals are identified using the stoneley waveform logs. In addition to these, core data has also been used as physical check on the basement properties. This complete workflow along with the Fracture intensity modeling workflow helps in determining the reservoir quality and the fracture network in the area (Fig 3)

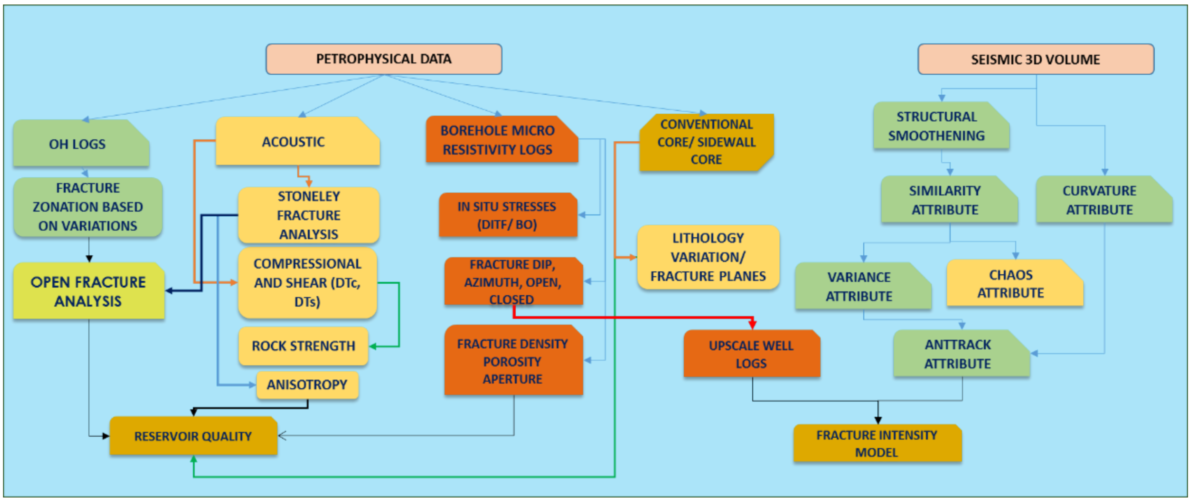

Fig 3: Integrated Fracture modeling workflow

Seismic data interpretation was carried out to generate various seismic attributes viz., curvature, similarity, variance, AntTrack™ , etc. which highlighted the discontinuities present in the area and brought out various fault trends present in the area. These attributes indicate continuity of discontinuities down to 300m from Basement top, beyond which noise appears to dominate. AntTrack™ volume finalized after few no. of iterations and this is used as the final seismic output for the fracture intensity model.

Out of six key wells drilled into basement, formation resistivity image logs are available in four wells. The entire workflow adopted helps in characterising the basement reservoir and distribution of fracture intensity. It also helps in understanding the role of faults and fractures in migration and accumulation of hydrocarbon in the basement reservoir.

Case study

Formation micro resistivity image logs available for four key wells have been used to pick fracture dips data. These logs point out that the major trends of fractures are along NNW-SSE and minor trends viz., NE-SW and NW-SE in wells WELL-A, B, C, E and F while in WELL-D fractures show a E-W major trend and NNW-SSE minor trend. Existence of E-W as major strike trend is due to the presence of E-W trending transfer trends in vicinity to this well. Fracture dips data was used to generate upscaled well logs which was subsequently populated into the AntTrack™ volume generating a robust Fracture intensity model.

In WELL-E and WELL-F, lying close to the Mumbai High east fault in the Mumbai High field, NW-SE and ~E-W trending fracture trends have been observed. Both the wells had hydrocarbon shows which is indicative of the hydrocarbon accumulation in this area. WELL-E has intersected fault damage zone and has shown good hydrocarbon potential from both weathered and fractured basement. Whereas

WELL-F did not punch through discrete fractures as observed in core studies. However implicit fractures have been identified, though most of them are filled with secondary silica and calcite leading to diminishing of permeability.

WELL-A has been drilled ~150m within Trap section with gas indications observed during initial production testing. Hydrocarbon shows at few intervals were observed in the ditch cutting samples. The FMI™ image log indicates presence of fractures in the entire interval varying in dip angles with fractures dipping 40°- 90°. The fracture strike rosettes indicates variation of strike trend from NNW at top, conjugate NNW and E-W in the middle and NE-SW towards the bottom of the basement section. Fracture intensity section along the well has been validated and shows a reasonably good match (Fig 4).

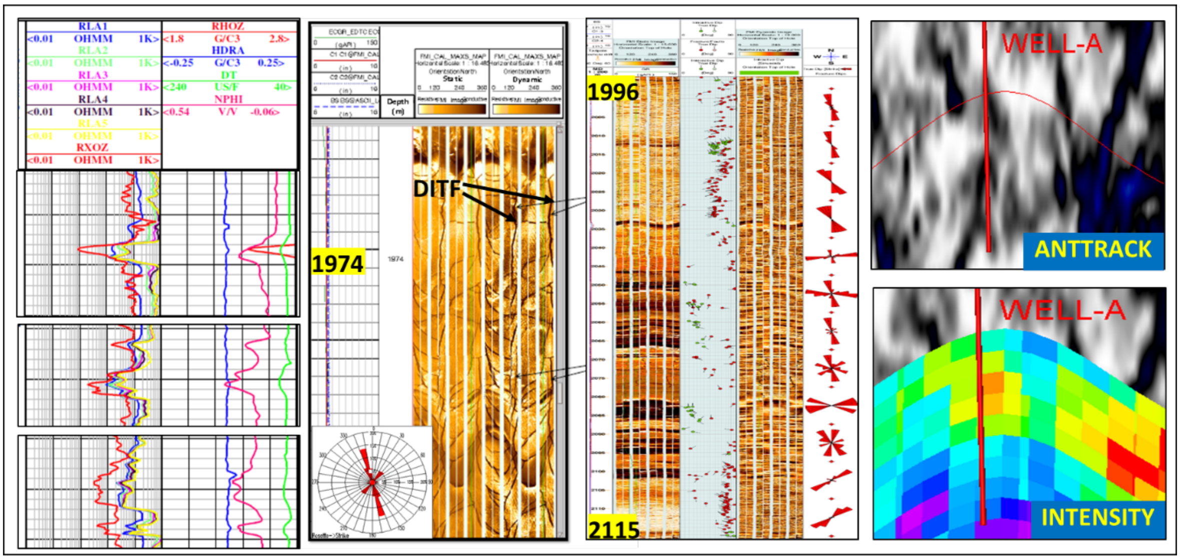

Fig 4: Log analysis of WELL-A indicating possible fracture intervals and their calibration with the Fracture intensity model

FMI™ image log data of WELL-B indicate natural fractures encountered at the entire interval appeared to be mostly resistive in nature with few conductive intervals. Fracture dips in this well range from 40-85° with fractures striking along NNW-SSE is in confirmation with the SH_{max} orientation. Deccan Trap was encountered in this well. Hydrocarbon shows reported in the cuttings at various intervals as seen in the master log and image log were calibrated and matched fairly well with in ant track and fracture intensity volumes (Fig 5).

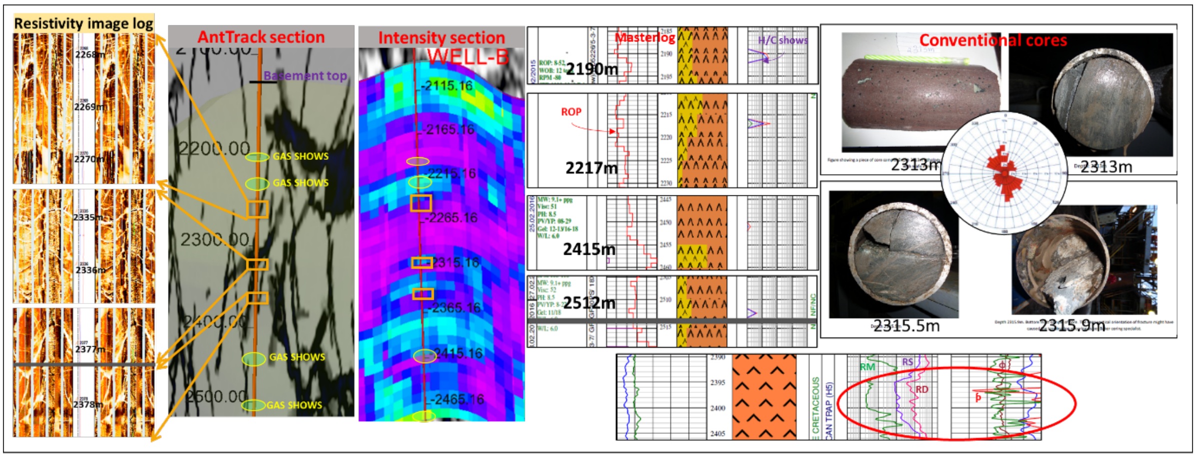

Fig 5: Log analysis, core data analysis and calibration with AntTrack™ section in WELL-B

The fracture intensity model was calibrated with the existing well data and thus the validation of the model was ascertained.

WELL-C and WELL-D were subsequently planned on the basis of the integrated fracture intensity model. Both the wells produced hydrocarbon from basement section. In WELL-C basalt while in

WELL-D granitic gneiss was encountered. Encouraging results from these wells with completely different lithologies demonstrate that both of these lithologies have undergone geomechanical changes and have led to development of dense fracture network responsible for the porosity and permeability of the reservoir. In WELL-C, which yielded commercial quantities of hydrocarbon from the basement interval depicts presence of dense fracture cluster from the formation resistivity image logs and open fracture intervals identified from the Stoneley waveform analysis. From the PLT log it has been observed that hydrocarbon entry is limited to ~2000m depth which may be due to the presence of singular NNW-SSE fracture trend beyond this depth. Fracture in the zone extending to 2000m are supposed to be in dilation mode, whereas fractures below 2000m are either completely filled with secondary minerals or are not in dilation mode. These intervals when calibrated with the AntTrack™ volume and fracture intensity model show a perfect match (Fig 6).

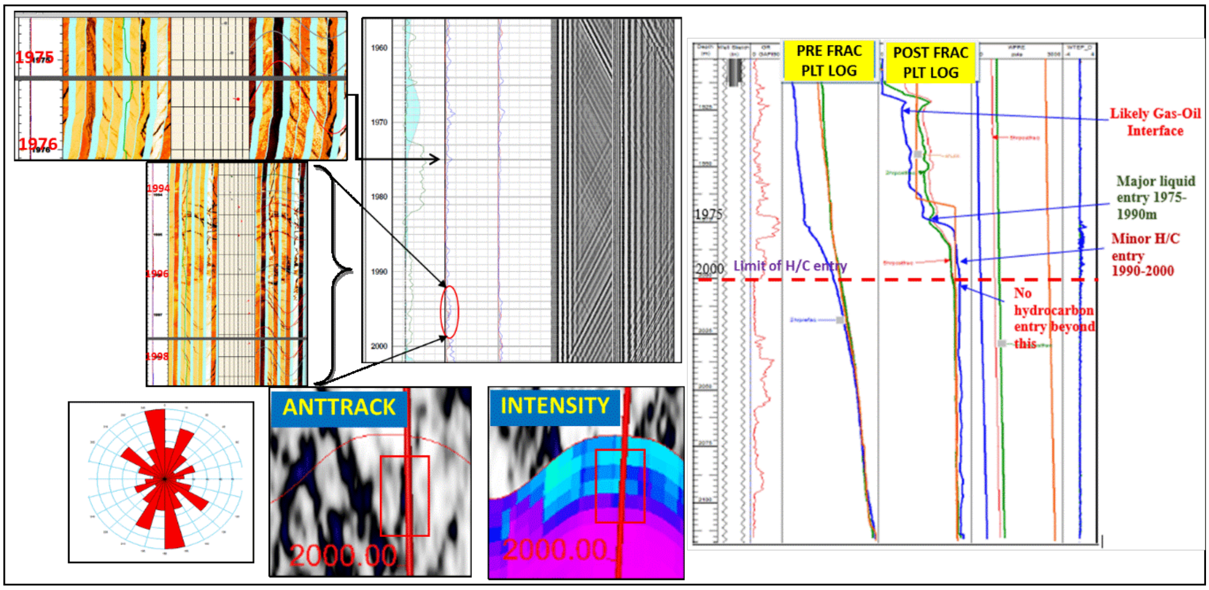

Fig 6: Log analysis and calibration from Fracture intensity model of WELL-C along with contributory zones identified from PLT log

FMI^{TM} image log, Stoneley waveform analysis, conventional logs and cuttings data in WELL-D were analyzed in detail. Fracture clusters were observed in intervals in the entire drilled section from resistivity image log. Correlation of these fractures with the Stoneley waveform analysis and conventional logs helps in identifying the contributing intervals. Resistivity values in the conventional logs shows a measurable change at fracture intervals (Fig 7).

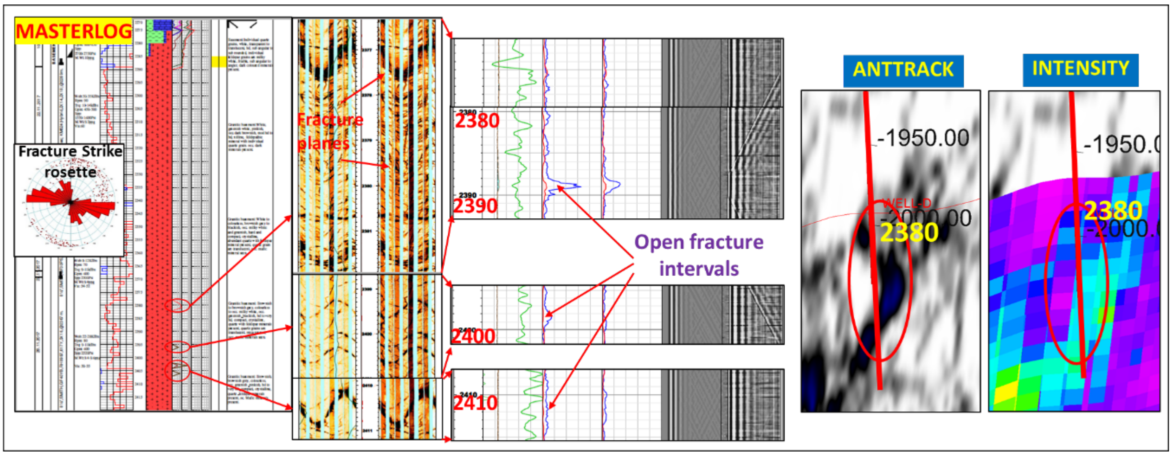

Fig 7: Validation of Fracture intensity model with the log data of WELL-D

Conclusion

The integrated fracture modeling workflow helps in deciphering the hydrocarbon prospectivity of South of Mumbai High area and arriving at few conclusions. Areas with good fracture intensity in vicinity to fault closures and fault intersections are the best locales for future exploration. The NE-SW to E-W trending faults act as migratory paths for hydrocarbon from the adjacent lows in this area. Thus fault intersections act as the most promising areas for basement prospectivity. Secondary porosity within basement has been developed by weathering and intense fracturing in the area owing to diagenetic and tectonic activities. Fracture intensity model along with available well information are best ways for characterising the areas with good reservoir characteristics. Production logging logs play an important role in determining the contributing fracture clusters, which in turn proves useful in drilling of wells in the area in future.

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