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Standardization of Workflow for Fracture Characterization in Basement: A Case Study from Mumbai High Area, Western Offshore Basin, India

Abstract

Mumbai High structure is a giant hydrocarbon field with established hydrocarbon in Miocene carbonates of L-III, L-II & L-I as primary reservoirs, the fractured Basement and Basal Clastics as secondary reservoirs. Mumbai High has witnessed four major tectonic episodes that have given rise to extensive fractured Basement reservoirs and that have been established as commercial producers. The present study has integrated the 3D seismic data with the well data and brought out the detailed Basement fault pattern of Mumbai High field and the probable locales of fractured Basement reservoir prospectivity. The interpretation workflow consists of three major steps, the removal of noise; calculating structurally oriented edge detection attributes; and the improvement of the fracture imaging in the discontinuity volume with an enhanced Automated Fault Extraction (AFE) algorithm. The orientation of the extracted fracture clusters were validated with the information derived from FMI log. The interpretation can be the reference for understanding of hydrocarbon charges within fractured Basement and also for designing of future wells.

Introduction

Mumbai High is situated at the western offshore of India; it is a giant field producing hydrocarbons primarily from multilayered Middle Miocene carbonate reservoirs as primary reservoirs, Basal Clastics and fractured Basement as secondary reservoirs (Figure 1). Although commercial accumulation of hydrocarbons from Mumbai High naturally fractured Basement reservoirs were established in the earlier days of the field history, focused efforts to exploit the full potential of this play have only begun in recent years. There are many naturally fractured Basement fields discovered globally by serendipity, but over the years, there has been a concerted effort by the Geoscience community to understand the origin, occurrence, distribution and commercial potential of Basement play, which led to a comprehensive understanding of the various aspects of the petroleum system of naturally fractured Basement. Basement was characterized into three major groups: Granite/Granite Gneiss, Phyllite/Schist and Basalt as shown in Figure 2 (Singh Uday et. al., 2017).

The basic structural fabric of Mumbai High is characterized by the imprints of the four major tectonic episodes witnessed by the basin viz.
1. NW-SE trending Dharwar rift phase
2. NS to NNE- SSW Aravalli Trend,
3. ENE-WSW fault set corresponding to Narmada trend
4. 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 (Vasudevan K et.al., 2012)

This paper focus on improvement of the fractured Basement imaging and calibration of fracture orientation with available FMI log data. The faults or fractures, result of tectonic activities and weathering or hydrothermal circulation (Satyanaryana P., 2010) were mapped and visualized in the form of 3D individual fault or fracture planes.

Methodology

The interpretation workflow involves three major steps in sequence, which are noise removal; structurally oriented edge detection attribute calculation; and fracture imaging enhancement with Automated Fault Extraction (AFE) algorithm (Dorn et al., 2012). The edge detection class attribute is particularly sensitive to noise. Coherent and random noises in the data may degrade and misguide interpretation result, especially on legacy seismic data (Dorn et al., 2017). The noise removal process is structurally oriented, where the de-striping processes and the statistical filtering is done by considering the local dip and strike (Dorn, 2018). Amplitude information at highly dipping areas associated with lithology and fluid variations are preserved after noise removal. This conditioning process is critical especially when the target is within the fractured Basement.

The Horizon Edge Stack (HES), a structurally oriented edge detection attribute is calculated from the conditioned seismic data. The attribute calculates the sample to sample amplitude changes in lateral directions and reiterates the cross shaped operator calculations for every sample position along the vertical axis. If a discontinuity calculation is done on a horizontal planar segment in a seismic volume and local horizons are dipping, the transition as the horizontal calculation plane crosses from peak to trough in the dipping seismic event will be detected and imaged as a discontinuity. HES may help in revealing the subsurface geomorphology and related geological discontinuities visualized on the horizon edge stack with faults or fractures.

The conventional manual 3D interpretation have trace bias because the reference is usually on inline and crossline, whereas actual fault trends varies from strikes and dips, the image of the fault discontinuities rarely restricted to inline and crossline directions. Manual interpretation for the larger volume having complex tectonic setup can be the tedious. General edge detection attribute can be better reference than seismic in fracture interpretation but it does not support auto extraction of 3D fracture planes. The attribute also has stairs-steps look-alike feature at vertical direction due to its slice-based calculation approach. Therefore, the fracture image can be further improved by using windowed Radon transform with AFE algorithm. The radon transform computes projections of an image matrix along specified directions. Arbitrary slices are extracted from the data where the fracture signals are projected onto these preferred slice orientations. The improved fracture probability is then written back into the sample space matrix. This accurately images fractures, regardless of dip, and improves its resolution besides signal strength in the output fracture probability attribute. The output probability volume supports the auto extraction of 3D fracture planes. The planar feature of the fracture, as well as its minimum accepted size can be user-defined. Maximum difference in orientation for two groups of sample points can have and still be considered part of the same planar feature if fall within the tolerance. The output fracture probability volume supports the auto extraction of the 3D fracture planes. Batch analysis of the extracted fracture planes can then interpreted with Rose diagram (Darmawan, 2017).

Results

The HES attribute co-rendered with seismic (Figure 3) shows the NW-SE trending doubly plunging anticline structure and associated faults. The main faults are closures which separated the field into different hydrodynamic systems. The depth slice also outlined geomorphology of the area, including subtle features. Figure 4a shows the areas of high density fractures in the HES attribute depth slice. Fracture probability slice derived from enhanced HES attribute revealed the fracture density network with white colour indicating higher score in probability (Figure 4b). Further the probability attribute co-rendered with the seismic is used for quality check (Figure 4c). The crispness of the image allows the auto-extraction of fault/fracture planes. Over thousands of small scale fracture lineaments were extracted within the area and were represented by different colour stripes in Figure 4d.

Detailed analysis can be done when checking the wells and the fracture probability in 3D. Small rectangular cubes with the probability volume have been created around the wells. The fracture planes extracted within the cubes were filtered and analyzed with Rose diagram. In Figure 5, the

Rose diagrams show strike orientation of fracture planes from small rectangular cubes around the wells and comparison with the information derived from image logs of well BH-B and BH-D. The fractures observed at FMI logs have been represented as well tops along the well path and QC was done, against the arbitrary sections of the fracture probability co-rendered with seismic. The orientation of fracture clusters at well BH-B (excluding the lower part of the cube) matches with the orientation shown at NE 20°. The orientation of fracture clusters at BH-D also matches with the observation from FMI log at about NE 70° (Figure 6).

With the QC at wells, the result can be used to display fracture density network throughout field (Figure 7). The interpretation result can be utilized to understand the hydrocarbon charges at the area where the barriers created by the fracture zones can be supported by geological model and justified with the wells. Based on the interpretation, future Basement wells can be design to penetrate through high density fracture zones.

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Conclusion

The fracture probability volume is able to capture the fault/fracture lineament within Basement. The orientation of fractures in seismic scale is consistent with the interpretation from FMI data. The attribute along with extracted fault/fracture point sets are able to provide additional information for the understanding of hydrocarbon charge and potential well planning.

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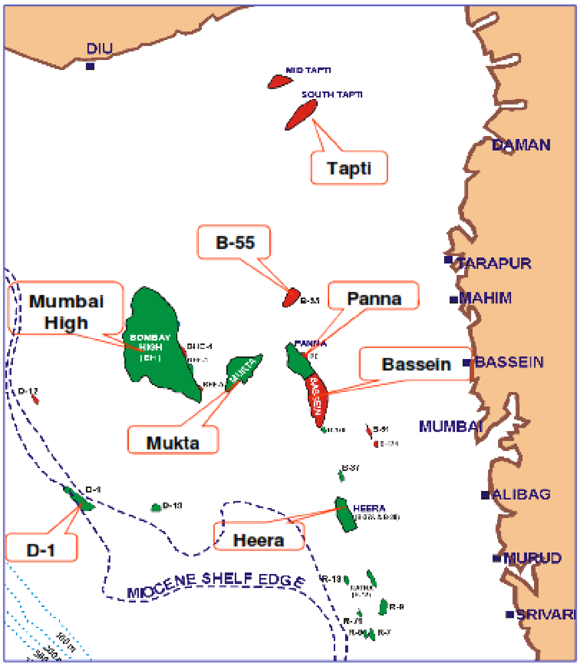

Fig.2: Mumbai High Basement composition map

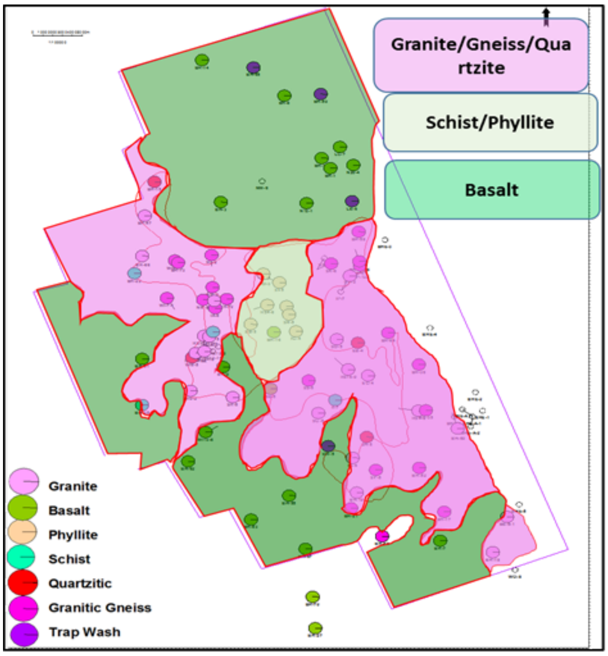

Figure 1: Index Map of Mumbai High Field.

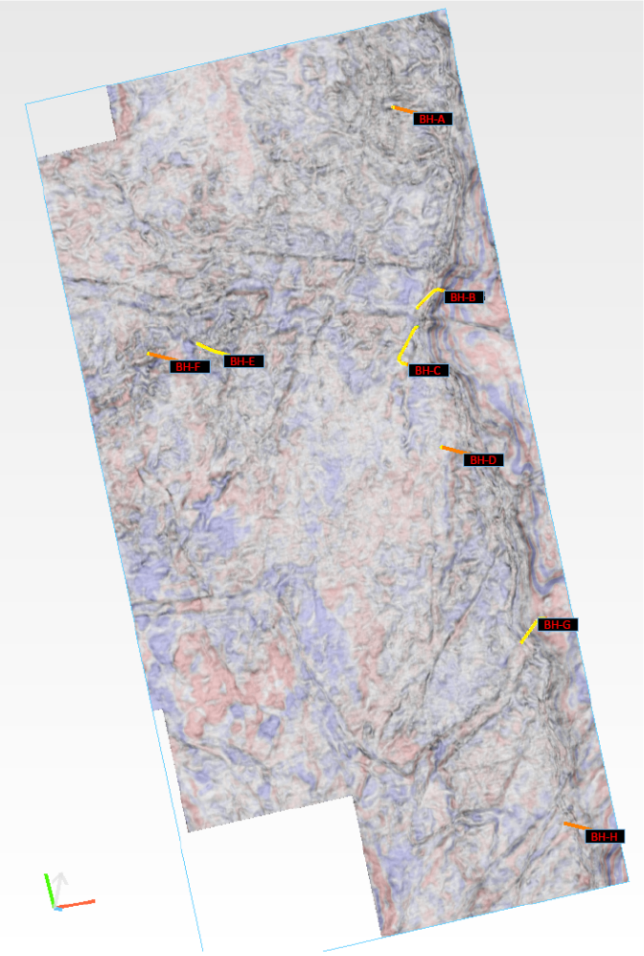

Figure 3: Depth slice of HES co-rendered with seismic, along with 8 well paths (BH-A to BH-H).

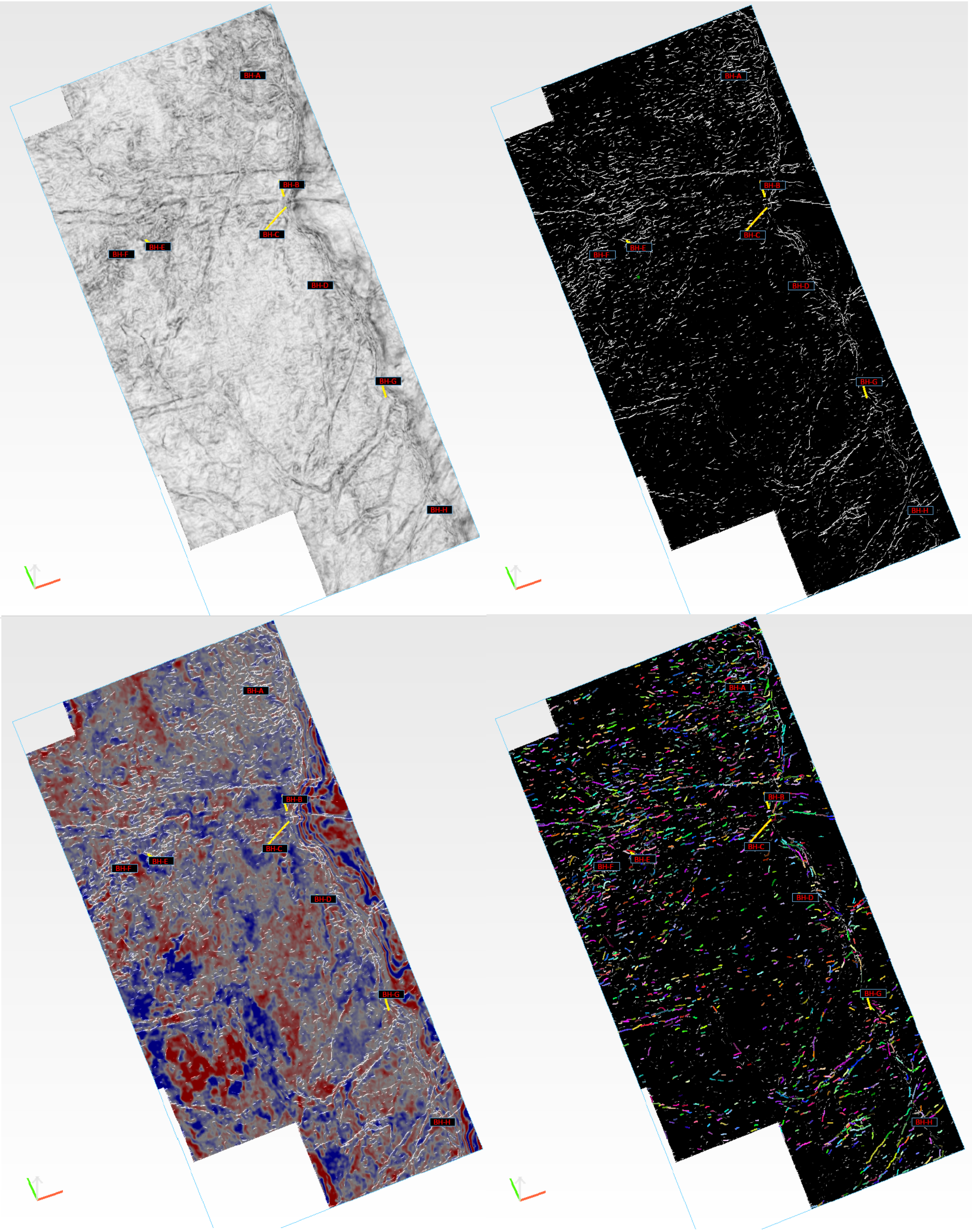

Figure 4: Depth slice from different volumes (a) HES attribute, (b) Fracture probability, (c) Fracture probability co-rendered with seismic, and (d) Fracture probability with various fault/fracture planes extracted and clipped to the slice

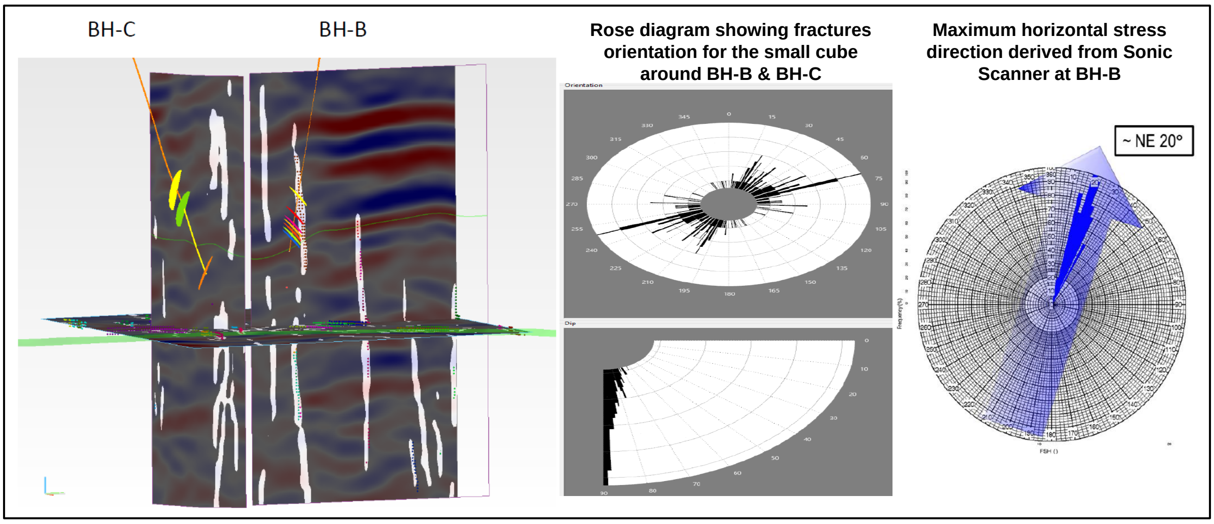

Figure 5: Rose diagrams shows strike orientation of fracture planes from small rectangular cubes around the well BH-B & BH-C and comparison with the information from image log. The orientation of fracture clusters at BH-B (excluding the lower part of the cube) agrees with the maximum horizontal stress orientation shown at NE 20^0. The NE 70^0 coming from the same rose diagram is actually orientation of fracture clusters below BH-B.

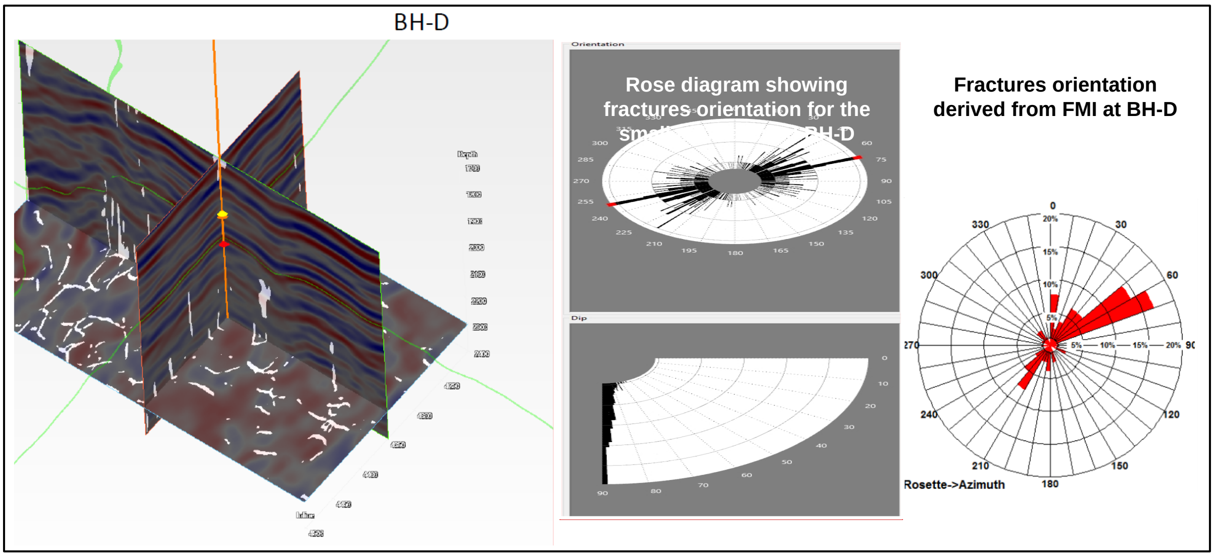

Figure 6: Rose diagrams shows strike orientation of fracture planes from small rectangular cubes around the well BH-D and comparison with the information from image log. The orientation of fracture clusters at BH-D also agrees with the observation from FMI log at ~ NE 70^0.

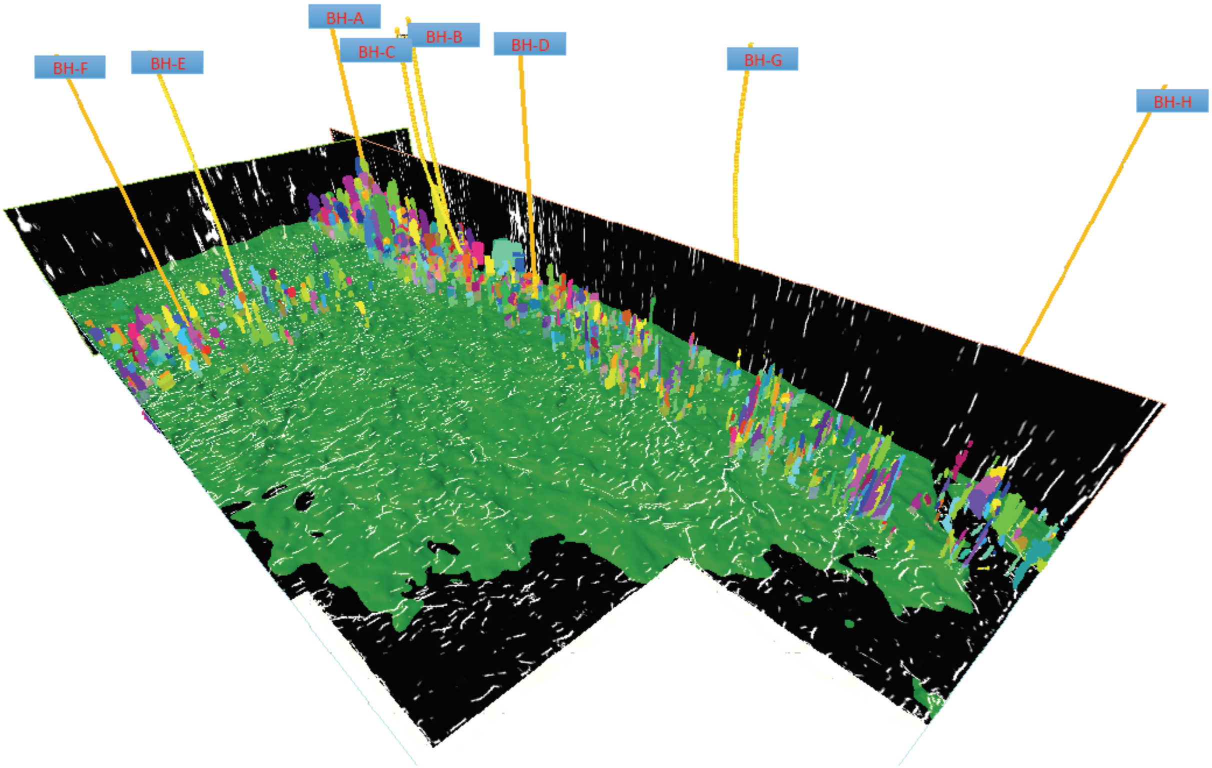

Figure 7: A perspective projection of the study area, with the top of Basement horizon shown in green and the selective fracture planes around the 8 wells.