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Mumbai High basement reservoirs: A qualitative approach for generating fracture model using Discrete Fracture Network modeling.

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Abstract

With a significant number of wells drilled and proven to be hydrocarbon bearing in basement, Mumbai High field is one of the priority areas in Western Offshore to prove and extend the concept of basement hydrocarbon accumulations. Mumbai high basement, a milieu of granitic/ metamorphics/basaltic basement is hydrocarbon bearing wherever major regional tectonic cross trends are observed.

This paper describes a methodology of DFN (Discrete Fracture Network) modelling using seismically driven reservoir characterization and integrated with geological and petrophysical data to evolve a robust basement fracture model. The model thus prepared calibrates well with production pattern in basement wells tested in the area and may be of immense help in planning and exploiting reserves of the field.

Usefulness of the derived seismic attributes is illustrated on a basement reservoir where a new well was recently drilled.

Introduction

The western continental shelf margin of India is an Atlantic type margin featured by longitudinal extensional faults in parallel sets giving rise to a series of narrow horst and graben structures. The style of faulting is controlled by three major orogenic trends in the western part of the Indian shield: NE-SW Aravalli, ENE-WSW Satpura, and NNW-SSE Dharwar trends. The tectonic elements defining basement architecture of Mumbai High are in agreement with the regional tectonic grains (figure 1). Basement hydrocarbon potential have been established in a number of drilled wells along the Mumbai High east boundary fault. Analyses of FMI logs of basement interval drilled in two wells in the area have helped decipher the principal stress direction as NNE-SSW which is validated by borehole breakout studies and anttracked attributes (figures 2 & 3). It can be considered that major fractures have genetic linkage to the Dharwar trend while the Aravalli and Satpura trends have generated fractures offsetting the earlier ones thus creating the much needed fracture mesh for hydrocarbon accumulation. The real challenge of delineating Mumbai High basement reservoirs lies in their uniqueness of fracture connectivity which is again related to basement lithology , density, aperture and length of fractures.

The present study has made an attempt to create a robust fracture intensity model after conditioning the CRAM (Common Reflection angle Migration) reprocessed seismic data by Gaussian smoothing and generating an anttrack volume . This antrack volume was the input for DFN (Discrete Fracture Network) modeling combining seismic attributes with petrophysical and geological inputs. The fracture model thus generated successfully explains hydrocarbon accumulation patterns in basement wells drilled in this area.

Methodology

The input data for this study is Mumbai High 3D pre stack time migrated data (PSTM) volume reprocessed using CRAM method. Faults and natural fractures can have significant effect on the permeability of reservoirs and it can have impact on productivity and efficiency (Neves et al., 2006; Chopra and Marfurt, 2007). Fractures occur at many scales but most of them are below the seismic resolution and thus are not easily visible in a standard seismic display (Singhal et al. 2010). Seismic attributes based on discontinuity principle provide useful tools to characterize faults and fractures (Hakami et al., 2004; Chopra and Marfurt, 2007; Basir et al., 2013). Ant Track is an important attribute, which can be used to extract information about faults and fractures from seismic data. The accuracy and quality of these seismic attributes are directly proportional to the Signal to Noise ratio of the seismic data.

The data was conditioned with Gaussian smoothening method guided by the local dip and azimuth to increase the continuity of the seismic reflectors. It reduces the structurally oriented random and coherent noise and increases the continuity and visibility of faults and fractures by preserving and at the same time sharpening the edge. The relative acoustic impedance was applied on conditioned data to boost the more coherent low frequencies relative to high frequency signals. The conditioned data was used as input for generating Variance volume and Chaos volume for edge detection. These two discontinuity volumes were combined to generate the final anttrack volume after a number of iterations (workflow in figure 4). Model builder was used to prepare the velocity model for converting time to depth volumes using time – depth data, RMS (stacking velocity) and calibrating with well picks. Mapped fault framework has been used as an input for preparation of Geological model.

The next step included analysis of image logs of three wells (wells B, C and D) and other petrophysical data to decipher the basement lithological composition, orientation , total porosity and fracture porosity, length and aperture of fractures, and determining their density variation spatially and with respect to geological controls. Fracture intensity properties based on image log data analyses of the three wells were computed and intensity logs generated (figure 5). Analysis of correlatibility between seismic attributes and petrophysical properties using supervised ANN (Artificial neural Network) tool helped identify and organize the best fracture drivers.

For the purpose of Discrete Fracture modeling, a 3D structural model (Basement top to 300m below) with cell size of 50mx50mx6m has been created for analyzing the data which was used to statistically model the 3D fracture patterns. Faults extracted by AFE (Automated Fault Extraction) tool was populated in the 3D model. A threshold value of 20m cut off based on histogram analysis was adopted for the purpose of DFN modeling. The fracture properties, viz; fracture length, fracture width, and fracture density were upscaled into the 3D geological model to create the Discrete Fracture Network (DFN) Model which captured the spatial distribution of fractures (generated stochastically) and associated heterogeneities.

Results and case study

Maximum amplitude extracted from anttrack volume along Basement surface in different time windows (figure 2 showing time slice in 20-60 ms window) indicates the presence of prominent lineaments and minor discontinuities / fractures in the study area. Common observations suggest basement prospectivity in fault damage zones and at junction of significant tectonic cross trends. Four sets of fractures were identified with major strikes in NW-SE and ENE-WSW direction and the final output in the form of discrete fracture model has been generated (figure 6). The model incorporated key basement wells in Mumbai High east area and provided an effective explanation to anomalous hydrocarbon distribution pattern within basement.

The wells A and C which are located on the fault damage zone adjoining Mumbai high east fault have flowed hydrocarbons from basement, whereas Well B has flowed water though being structurally shallower at basement level than the other two wells.. A close look at the fracture intensity of these three wells reveal significantly more discrete fractures and fracture intensity at wells A and C than observed at well B (figure 7).

Well D located in the middle of the study area middle of the study area was drilled in excess of 400m within basement but did not yield hydrocarbons from basement. DFN model seems to suggest absence of notable discrete fractures at the well though presence of implicit fractures (as evidenced from FMI log) is noted. However a detailed analysis of FMI reveals that the granite gneissic basement in this well is highly foliated and core samples reveal that all high angle fractures are filled with secondary silica and calcite, thus affecting permeability. The effect of weathering is observed deep down with leaching effects along fractures but probably there is issue of poor connectivity as evidenced from poor injectivity.

The wells E and F have produced oil and gas from basement without significant water cut. Anttack on basement surface and DFN model clearly demonstrates that both the wells have been suitably placed at the juncture of two major discontinuity cross trends (figure 8) Analyses of PLT data in conjunction with shear log interpretation in well F brings out a number of open fracture zones , even 200m+ within basement which may have contributed to flow of hydrocarbon justifying the 300m thickness of 3D structural model volume adopted for DFN modeling.

Well G was drilled right on Mumbai High east boundary fault junction with NE-SW trending lineament cross trend (reactivated Aravalli fault trend), a geologically similar setup as observed in hydrocarbon habitat near wells E and F (figure 8). Analyses of FMI and sonic scanner data validated this trend which is also evident in anttrack volume (figure 8). Fracture intensity at well bore simulated from total intensity model indicated fairly good fracture intensity at depths over 200m+ within basement which was validated by FMI, sonic scanner and real time drilling observations (figure 9).

Conclusions

Discrete fracture Network model provides a quick way to visualize the trends of faults and fractures, which are not visible in seismic amplitude information and can be used to optimize well locations, as in the case of well G. In this case study, DFN was effectively used to anticipate fracture intensity at well G which to fair degree of accuracy matched with well data. DFN as a tool can be of immense help to determine the effective fracture length and more accurate fracture porosity for determination of inplace volumes of basement reservoirs. Basement hydrocarbon accumulation is a complex function of basement lithological heterogeneity, localised stress-strain patterns with relation to major tectonic episodes and local weathering effects, all of which have a bearing on the final static model of statistically populated fractures. For a more accurate model, specific processing of seismic wide azimuth data using proper filters to capture the basement discontinuity frequency spectrum is needed. Calibration of seismic fracture characterization with well data in the form of oriented cores, VSP, image logs and shear logs and validated by PLT will lead to more accuracy in the static 3D fracture model which in turn will help predict fracture networking and provide real time solution to stimulation job planning at well bores.

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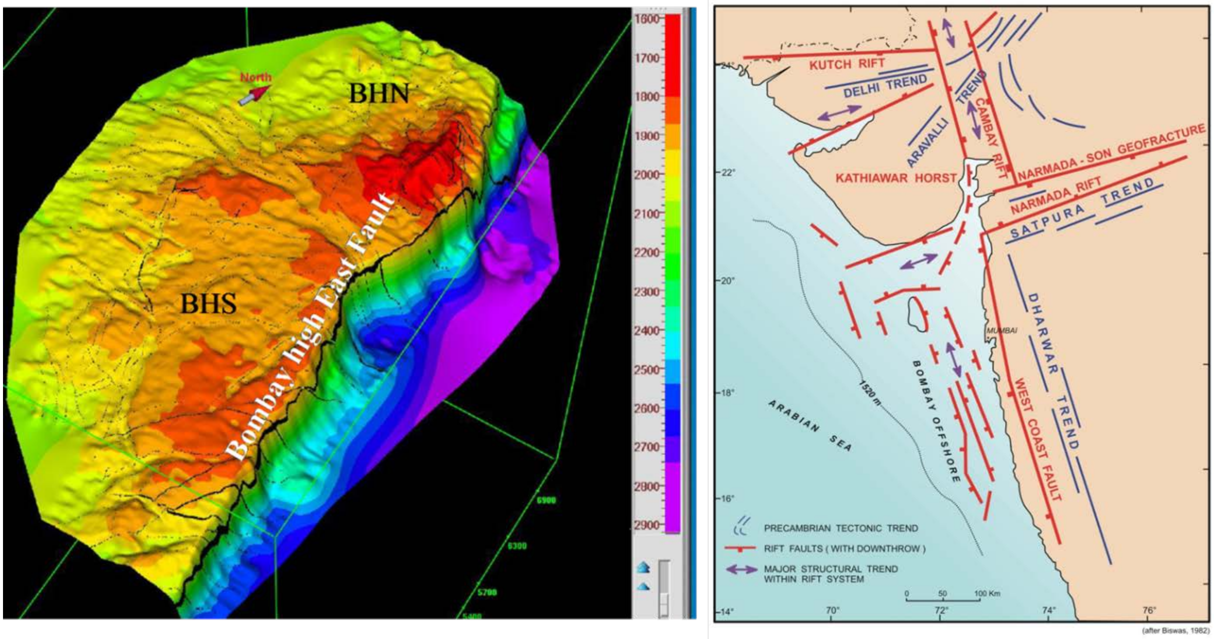


Figure 1: Tectonic elements of Mumbai high vis-a vis tectonic grains of Western India

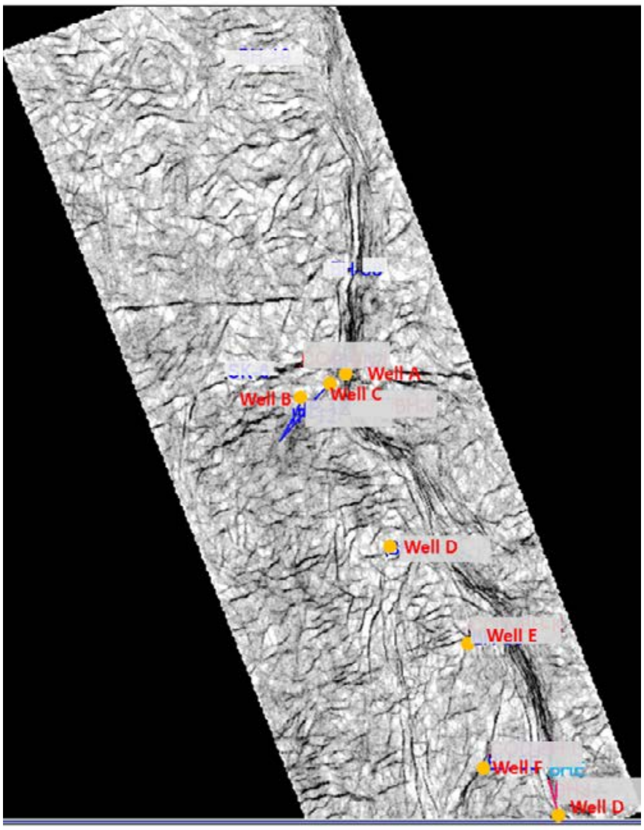


Figure 2: Maximum amplitude from anttrack volume for basement (in window 20-40 ms)

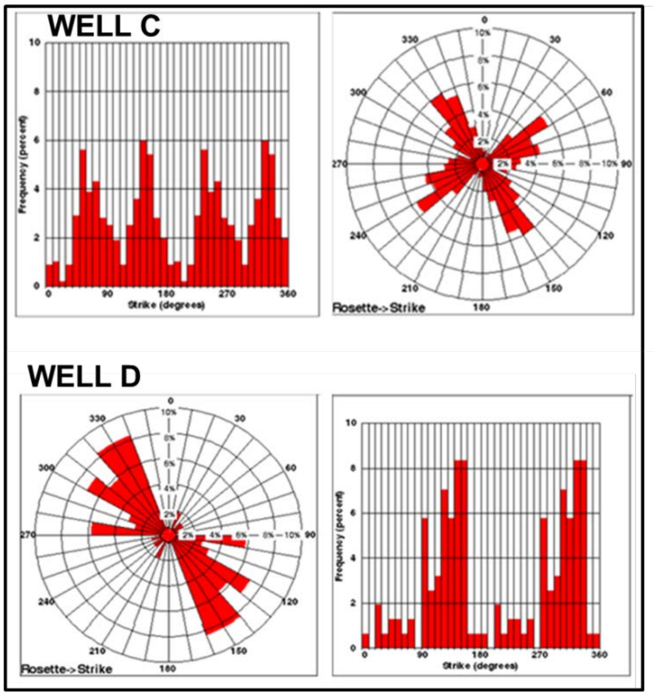


Figure 3: FMI interpretation of 2 wells drilled in Mumbai High east basement deduces principal fracture strike azimuth as NNW-SSE

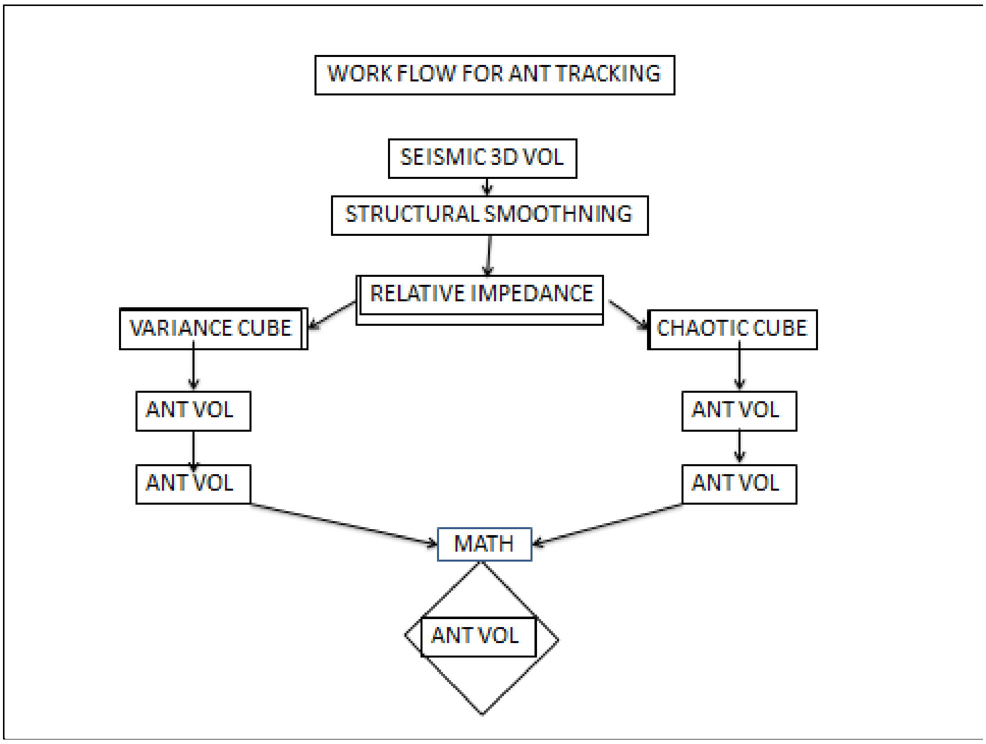


Figure 4: Anttrack workflow

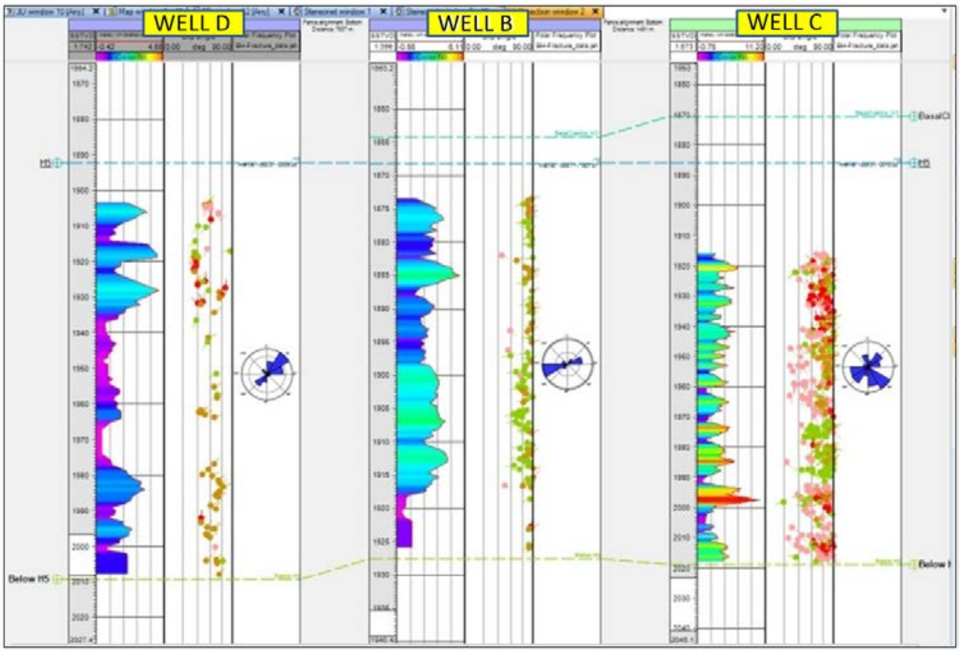


Figure 5: Fracture intensity generated at wells B, C and D

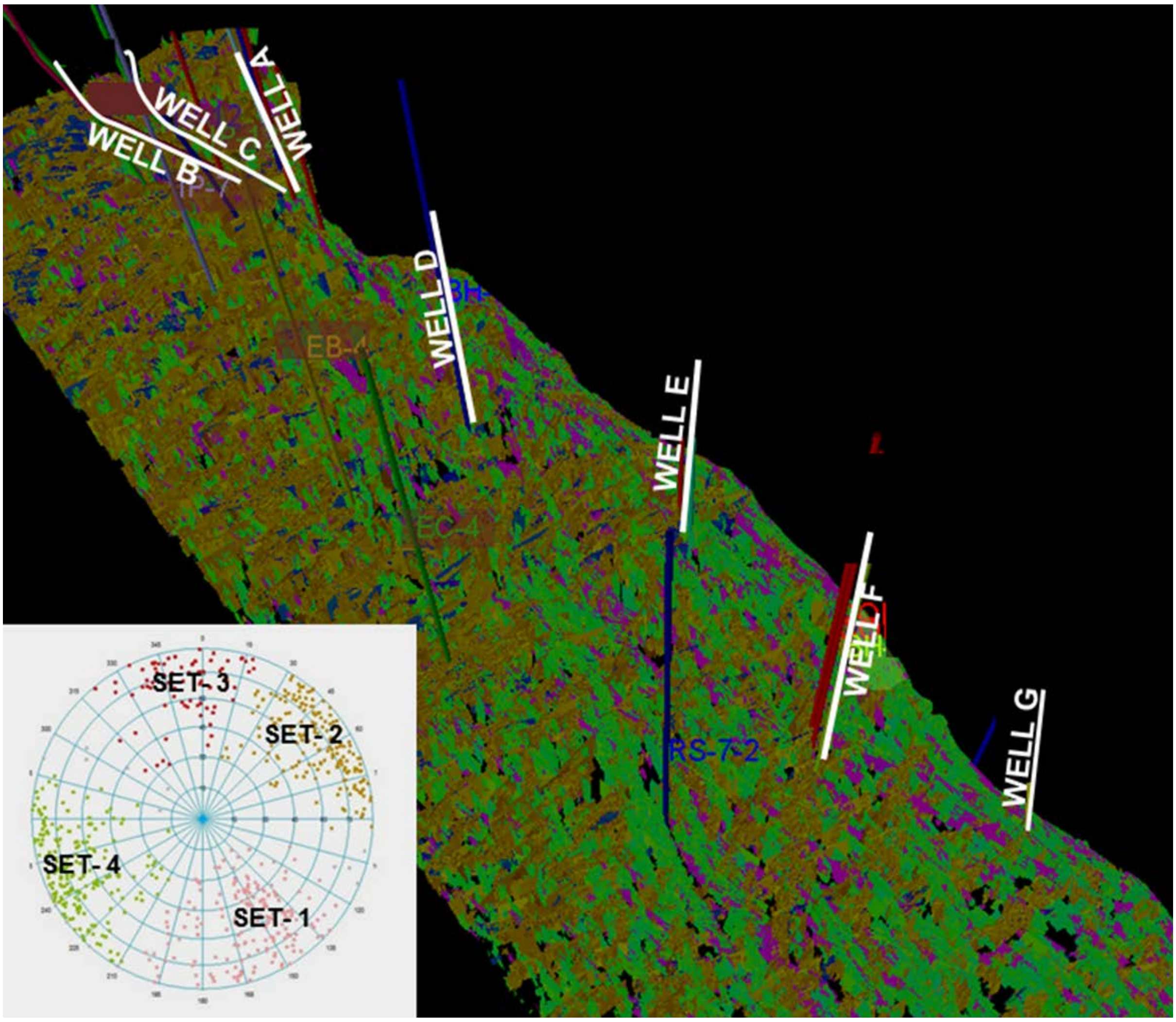


Figure 6 : DFN model of total fracture intensity

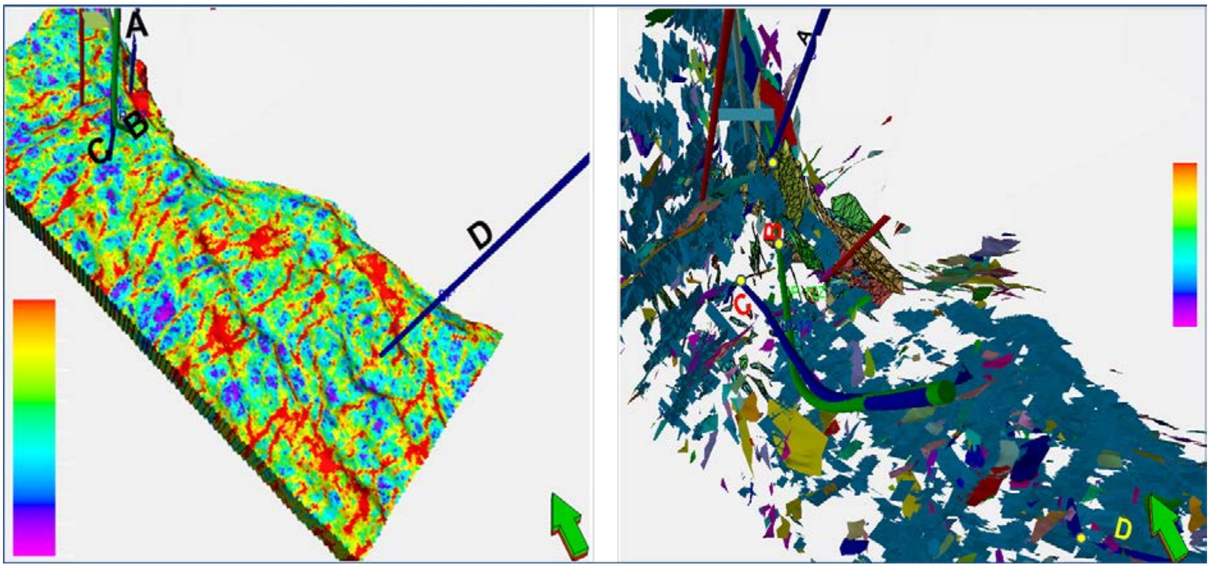
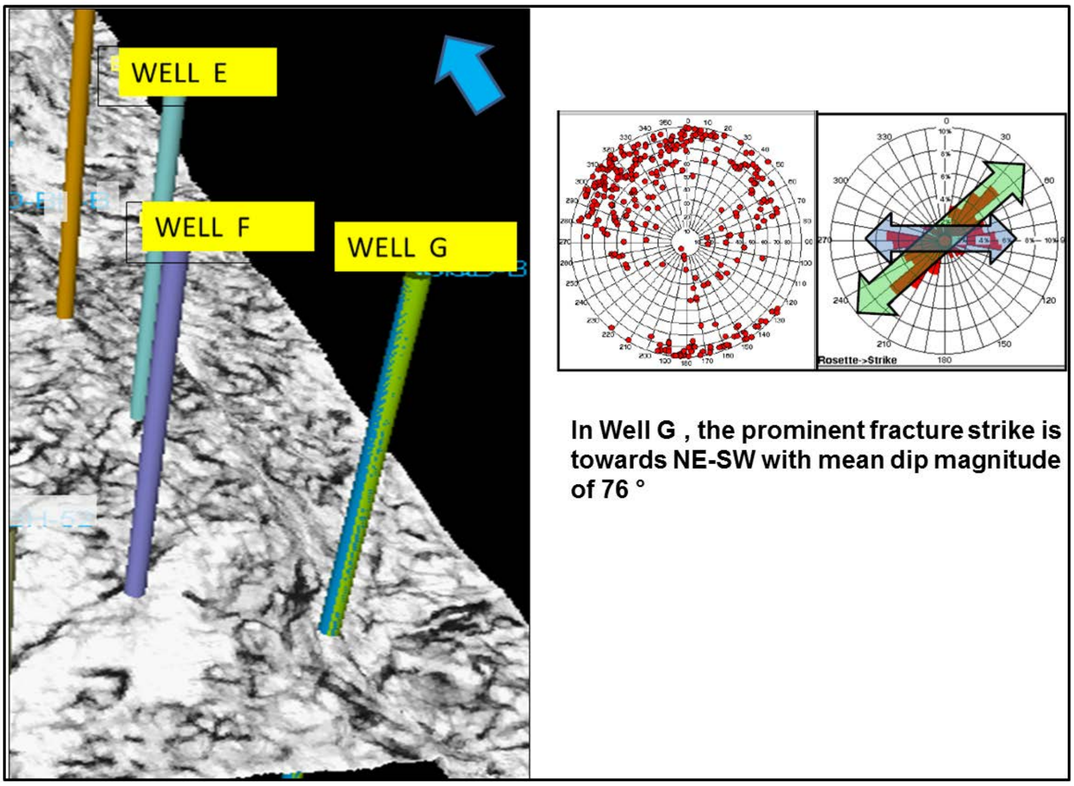
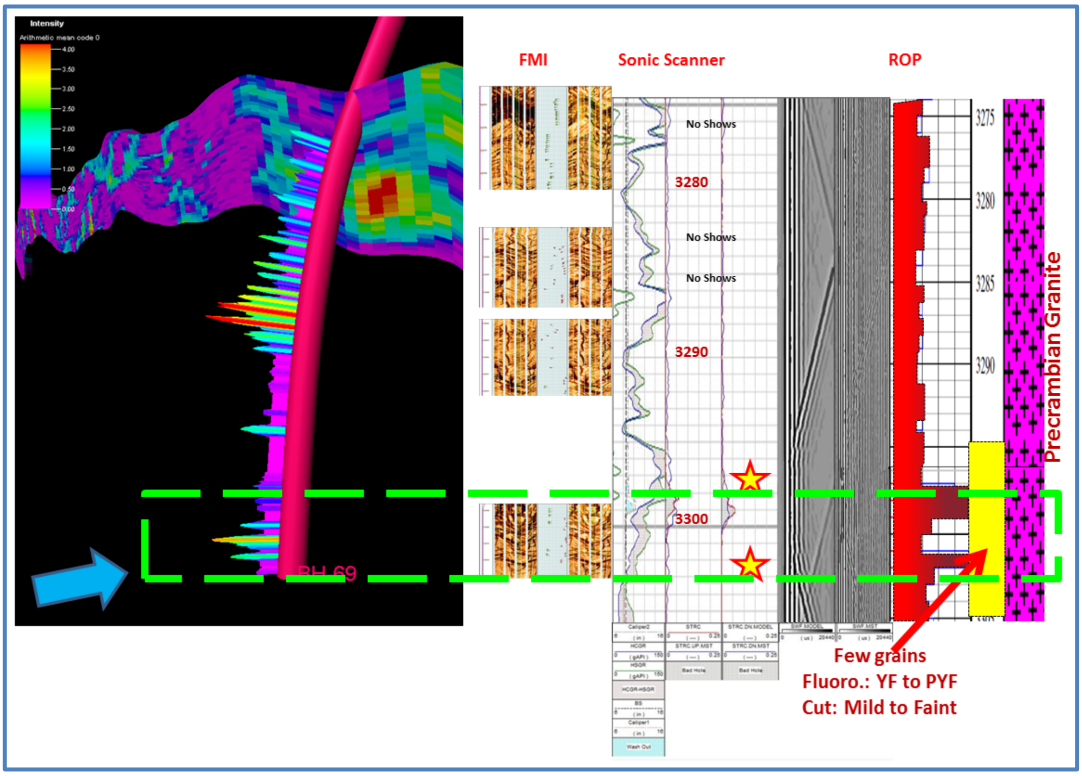


Figure 7 : Total fracture intensity and DFN on extracted fractures showing well locations A,B,C and D



In Well G , the prominent fracture strike is towards NE-SW with mean dip magnitude of 76 °

Figure 8 : Anttrack at basement surface showing lineament patterns in wells E,F and G and major fracture azimuth in well G



Few grains
Fluoro.: YF to PYF
Cut: Mild to Faint

Figure 9 : Fracture intensity from DFN model vis-à-vis petrophysical and drilling data in Well G