Effective Fracture characterization of basement reservoirs of Mumbai High: A case study

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Summary
Present study has been carried out to generate fracture intensity index from basic suit of logs for those wells in Mumbai High area, where no hi-tech data is available to generate fracture attribute. Resistivity based Fracture Intensity Index (FII) is generated and compared with FMI frack view along with sonic an-isotropy. Fracture Intensity Index(FII) log has been found in agreement with Frack View porosity and sonic anisotropy, thus establishing a methodology to quantify fractures from basic logs.

Introduction
Evaluation of fracture is the key to characterize a reservoir effectively for drilling, completion, development and stimulation of basement reservoirs. Present day logging technology such as Formation Micro Imager and Sonic Scanner provide fracture attributes but old wells do not have this hi-tech tool data. Qualitative fracture analysis from basic logs such as Caliper, Litho-density, Density Log, Uranium curve in Spectral Gamma ray etc. is possible but **quantifying** fracture from these logs is difficult. Present study is a case study from Mumbai High field, India which started producing hydrocarbons from naturally fractured granitic basement in 1987 with the drilling of a well exclusively for basement exploration.

Methodology
Electrical logs are sensitive to conductive anisotropic structures present in the rock formations both at macroscopic scale (such as bedding, faulting and fracturing) and microscopic scale (such as pervasive micro-cracking) as a consequence of depositional process and tectonic stress. ***Philippe A. Pezard (***1990)[1] formulated that such structures can be modeled by a set of equally spaced sub-vertical (Dip Angle>=60^0) conductive features of volume $\mathbf{Ø_{fv}}$ by the relation;

$$\mathbf{Ø_{fv} = [2*\{C_{LLS}^2 - C_{LLD}^2\}/(C_{LLD}*C_f)]} \text{----- } ❶$$

For spaced sub-horizontal conductive features (Dip Angle=<30^0) of volume $\mathbf{Ø_{fh}}$ by the relation;

$$\mathbf{Ø_{fh} = [\{C_{LLD}^2 - C_{LLS}^2\}/(C_{LLD}*C_f)]} \text{ ------- } ❷$$

Where C_{LLS} & C_{LLD} are conductivity from shallow & deep laterologs while C_f being fracture conductivity. C_f can be determined in the laboratory from host rock itself. There is no approximation possible for angle between sub-horizontal and sub-vertical **i.e.30^0 <fracture angle< 60^0**, therefore there is no **derivative of equation** [1] possible in range 30^0 to 60^0. In the present study, since $\mathbf{C_f}$ could not be determined in lab, it has been taken as an approximation as $\mathbf{C_m}$ (mud conductivity at formation temperature).

In the well BH-XX and BH-YY, FMI logs were available along with HRLA resistivity logs. $\mathbf{Ø_{fv}}$ has been calculated with Pezard method, using RLA2 curve as LLS and RLA5 curve as LLD. This value of $\mathbf{Ø_{fv}}$ has been compared and found to be in agreement with **Sonic Scanner anisotropy** and **FRACK VIEW** derived porosity. Generated Fracture intensity index log for well BH-XX and BH-YY is shown in **figure-1** and **figure-2** respectively.

Fracture Dip Classification
Based on LLD and LLS based anisotropy, fracture dip angle may be classified; $\mathbf{R_{LLD} > R_{LLS}}$ can occur in sub - vertical fractures (a dip angle >= 60^0), whereas a negative separation $\mathbf{R_{LLS} > R_{LLD}}$ in some interval can be attributed to presence of sub-horizontal fractures (a dip angle =< 30^0). Sub-vertical dips have been plotted with ***FII_SV (red curve)*** and sub-horizontal with ***FII_SH (blue curve)*** in last track of presented logs in figure-3 to 5.

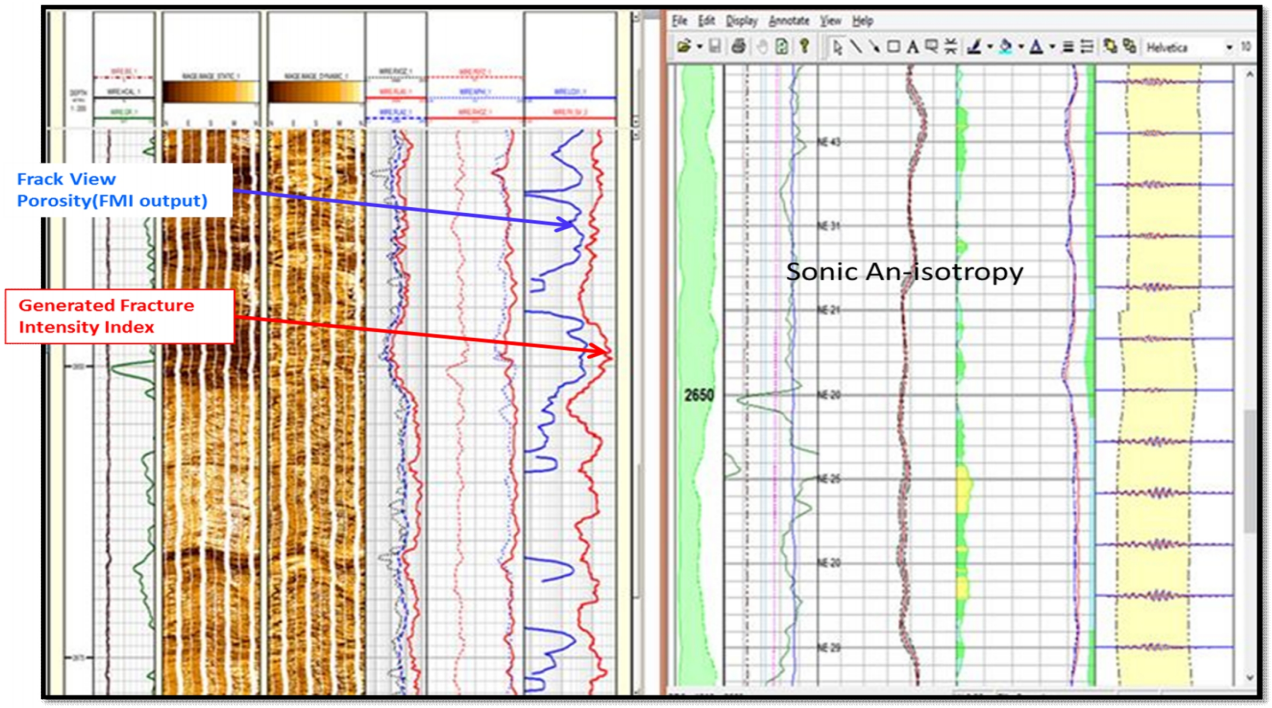

Figure 1: Comparison of Fracture Intensity Index log(red curve in last track) with Sonic Scanner anisotropy and FRACK VIEW porosity(blue curve in last track) (Well- BH-XX)

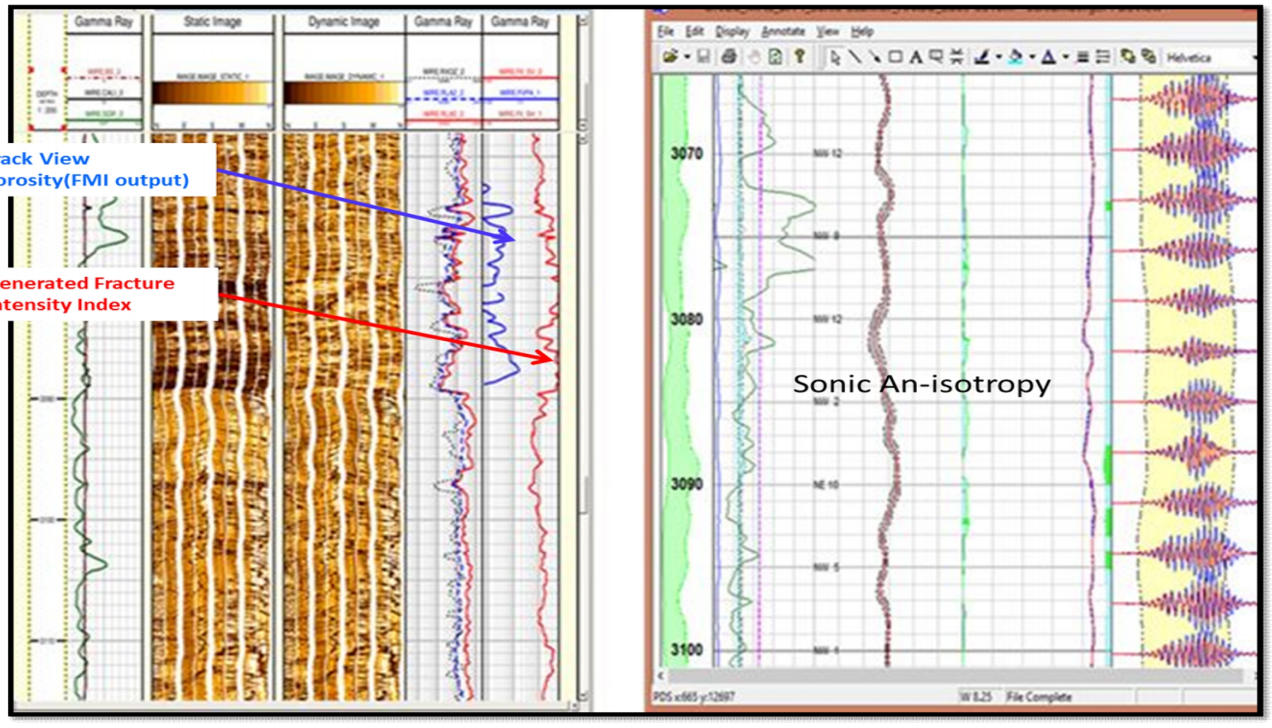

Figure 2: Comparison of Fracture Intensity Index log with Sonic Scanner anisotropy and FRACK VIEW porosity (Well- BH-YY)

Results and Discussion

Resulted FII log was compared with other data i.e. PLT data, conventional core data, testing results etc. Well wise observations for few of studied wells are discussed below;

Well- BH-A1

Fracture Intensity Index Log

Sub-vertical and sub-horizontal Fracture Intensity Index log has been generated using Pezard equations, showing presence of Sub-vertical fractures in the interval **1892m-1915m (shown in figure-3).**

Production Testing

Basement portion of well-BH-A1 was tested barefoot by placing packer at 1887m. Well produced oil and gas @461 BOPD with 337 GOR through 0.5" choke.

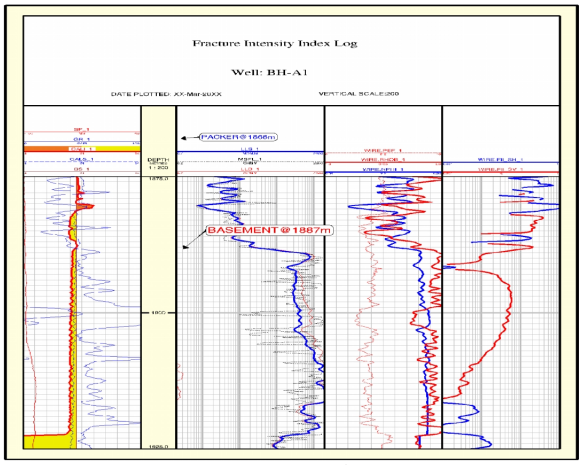

Figure 3- Fracture Intensity Index log of well-BH-A1.

Well- BH-A2

Fracture Intensity Index Log

Sub-vertical fractures have been observed from Fractured Intensity Index (FII) log generated by Pezard equation. FII log is showing very clear fractures in the interval 1925-1935m, 1952- 1988m and 1992-2029m, which has also been observed during production and injectivity logging**.** Well BH-A2 was additionally drilled from 2025m to 2127m after getting encouraging results in the basement section. Generated Fracture Intensity Index log is showing very good sub- vertical fractures **(figure-4).**

Production Testing

Interval 1919m-2020m was tested as object-I in well BH-A2, produced oil @ 523 BOPD and gas @ 48076 m^3/d through 1" choke during production testing. Interval 2025m-2125m was tested and produced @ 281 BOPD oil and 28,325 m^3 gas through 1" choke.

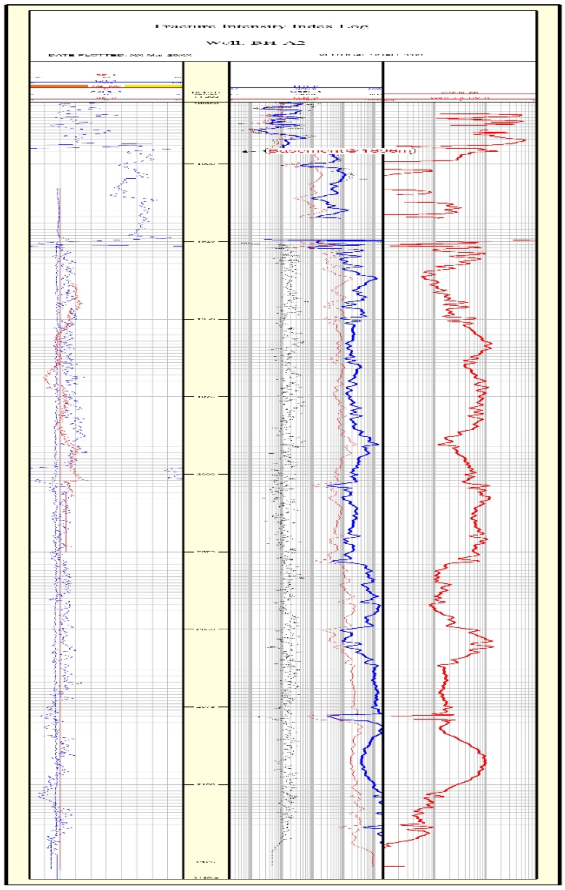

Figure 4- Fracture Intensity Index log of well-BH-A2.

Well- BH-A3

Fracture Intensity Index

Fracture Intensity Index log showing development of good sub-vertical fractures in intervals **1916m-1921m, 1930m-1935m and 1937m-1955m**. Some sub-horizontal fractures have also been observed in this well at interval **1924m-1926m and 1935m-1936m**. Generated FII log is shown in **figure-5.**

Production Testing

The well BH-A3 has been tested in two objects; Object-I interval 1924m-1961m barefoot testing and Object-II interval 1918m-1921m cased hole perforation@ 8spf.

Object-I interval 1924m-1961m, packer was set at 1924m in 7" liner, well produced approximately @ 250 BOPD oil and 2586 m^3 gas per day after acidization.

Object-II interval 1918m-1921m, well flowed @ 4267 BOPD oil and 52568 m^3 per day gas with 1"choke.

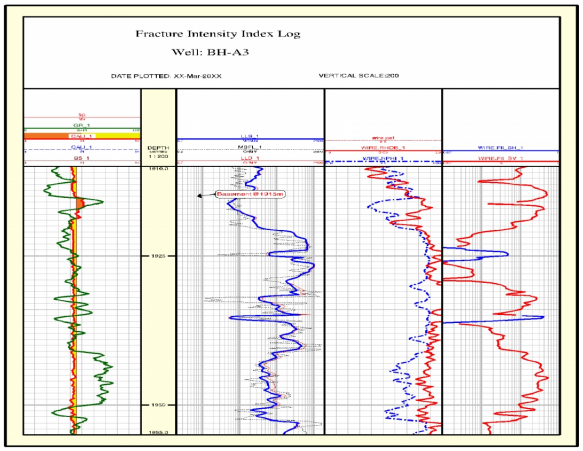

Figure 5- Fracture Intensity Index log of well-BH-A3.

Conclusions

- For quantitative generation of fracture intensity index, only Resistivity log is found suitable and methods using other logs are either lithology dependent or bound to other limitations.
- Resistivity tool (DLL generation tools) gives best response to fractures (invaded or healed with conductive minerals). Out of the two approaches using resistivity; Pezard method provides better agreement with production testing and core data reports. This is found best to generate fracture intensity index log of basement section Mumbai high area.
- FII is directly related with fracture porosity, although determination of absolute fracture porosity will need more data integration and calibration, this method nicely supports with production logging and conventional core reports.

References

1. Philippe A. Pezard and Roger N.Anderson ”In Situ Mesurements of Electrical Resistivity, Formation Anisotropy and Tectonic Context” SPWLA 31st Annual Logging Symposium, June 24-27,1990.
2. C. Boyeldieu and A. Winchester “ Use of Dual Laterolog for the Evaluation of Fracture Porosity in Hard Carbonate Formations” Offshore South East Asia 82 Conference, 9-12 Feb, Singapore
3. A. M. Sibbit “Quantifying porosity and estimating Permeability from Well Logs in Fractured Basement Reservoirs” SPE PetroVietnam ’95.
4. Pawan Dube, Soma Chatterjee et.al. “Log Derived Fracture Network Analysis for Basement in Mumbai High Area” Unpublished report, 2015.

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