# Fracture Modelling of Basement Reservoir in Mattur-Pundi Area, Cauvery Basin: A Holistic Approach

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## Summary

Exploration of Fractured Basement has gained momentum in Cauvery Basin after the significant oil production from Madanam Field. Cauvery Basin endowed around 7 fields which have produced oil & gas from Fractured Basement. The Basement exploration so far was based on drilling shows initially followed by cumulative fracture intensity within basement from Ant-track DFN studies. In the present work, a 1D-geomechanical study has been carried out and identified the Critically Stressed fractures in drilled wells in Mattur-Pundi area of Cauvery Basin, which are actually contributing for the hydrocarbon production. Further, the 3D fracture modelling was carried out by seismic derived Discrete Fracture Network Modelling with directional filters and identified Critically Stressed Fractures in the study area, which is a novel approach in basement studies. Chasing of Critically Stressed Fractures, which are the main hydrocarbon repositories, will certainly show the future trails for basement exploration.

## Introduction

Oil in Fractured Basement was discovered in Cauvery Basin way back in 1980 in offshore PY field, lying on offshore extension of Madanam ridge, as serendipity. It was followed by a series of discoveries on remaining basement highs. Mattur and Pundi field lie on rising flanks of Tanjore sub-basin adjacent to Kumbakonam ridge (Fig. 1). Pundi field witnessed success from 3 oil wells whereas Mattur field has produced oil in a single well from basement. This region has witnessed a major setback as several wells drilled on adjacent highs have gone dry. This suggests that a detailed knowledge of Critically Stressed Fractures (CSF) is required rather than mere presence of a culmination and random fracture intensity.

After the success of Madanam oil field, in which the average well production is ~115m3/d, the basement exploration has got boosted to look for similar plays on other basement highs. In the present study, the Mattur-Pundi area was taken up for studying the interaction of fractures and regional stress to look out for open and conductive fractures.

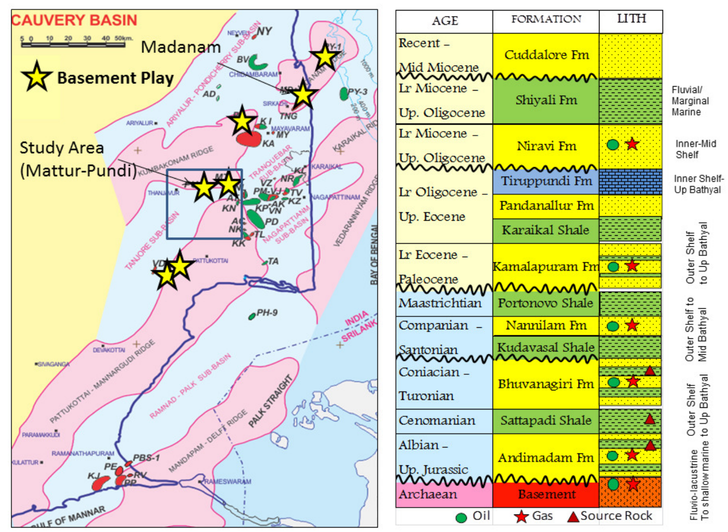


Figure 1: Tectonic map of Cauvery Basin showing Basement Prospects and study area. Generalized stratigraphy of Cauvery Basin on right side (Rangaraju et al, 1993).

## Geology and Stratigraphy

Cauvery basin is an intracratonic rift basin evolved during Late-Jurassic-Early Cretaceous break-up of Indian plate from East Gondwana and transformed into passive margin during Tertiary (Rangaraju et al., 1993). Syn-rift Andimadam formation is the main source rock in the entire basin which was deposited under shallow marine-fluviolacustrine conditions (Fig.1) during Late Jurassic- Albian rifting event. Andimadam wedges out against Basement highs such



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as the Mattur-Pundi high. The overlying thin Bhuvanagiri formation above basement, is mainly argillaceous with thin sands, which were also inturn oil producers in Pundi field. Bhuvanagiri formation is overlain by Thick Kudavasal shale which acts as regional seal.

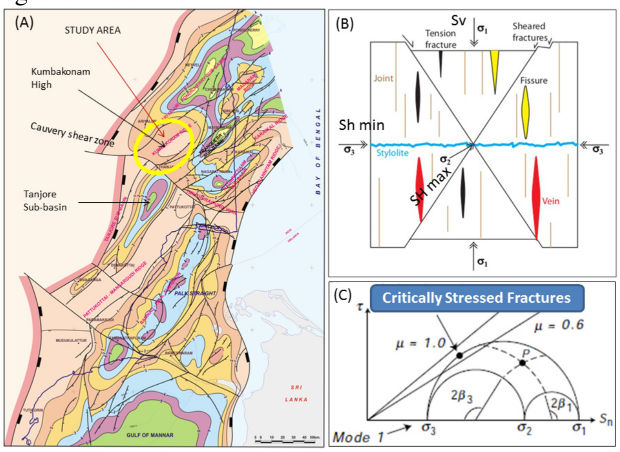


Figure 2: (A) Tectonic map of Cauvery Basin showing the presence of Cauvery Shear zone at study area (Prabhakar & Zutshi, 1993). (B) Different types of fractures in a normal faulting regime. (C) 3D-Mohr circle analysis to detect critically stressed fractures (Ferrill et al., 1999).

The basin is segmented into NE-SW trending horsts and grabens (Eastern Ghats trend) and were transected by NW-SE trending transfer faults (Dharwarian trend). The southern flank of Kumbakonam high in the study area is transected by E-W/WNW-ESE trending Cauvery shear zone, which is major regional fault which is also reflected in Bouger gravity maps (Rambabu & Lakshmi, 2004).

## Theory

For the accumulation of Hydrocarbons in basement reservoir, the essential pre-requisites are: (a) presence of good fracture intensity, (b) close to source rock, (c) presence of top seal, (d) presence of open fractures to hold and conductive fractures, which transmit fluid from source to reservoir, (e) structural entrapment to arrest the further migration.

The fracture geometry evolved by the tectonic events in any region. In a simple normal fault regime, a pair of shear fractures making acute angle to maximum principal stress ($\sigma 1$) and tensile fractures aligned parallel to $\sigma 1$ (Fig. 2B) occur. In folded regions, tensile fractures found in axial part where as longitudinal & cross-joints found at limbs (Price, 1967); while strike-slip regions are embedded with fractures like Riedel, P-shears, etc. Fracture geometry becomes complex and multi-oriented if the region experiences further reactivation. Fracture swarms can be found near fault zones, fold crestal parts, fault tips, transfer zones & transfer faults.

The orientation of fractures with respect to the present day stress-field makes the significant impact in holding or migrating hydrocarbons from them. The fractures which are experiencing high shear stresses by making acute angle with present day SHmax (called as Critically Stressed Fractures, CSF) and the those experiencing high normal stresses (dilational fractures, mode I) are collectively called as **Stress Sensitive Fractures** (Murry & Montgomery, 2012) which contribute significantly to fluid flow in the reservoir.

## Methodology

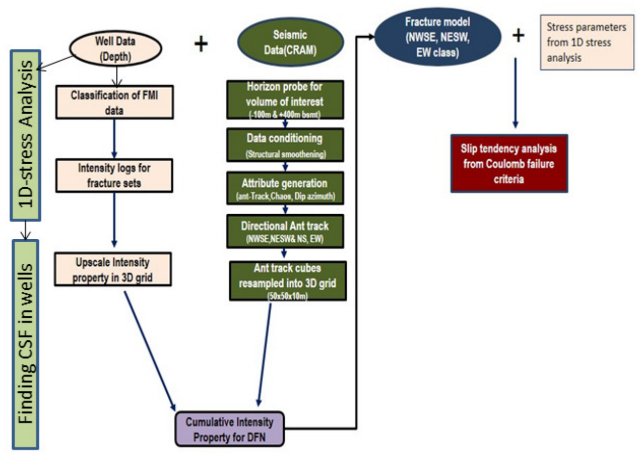


Figure 3: Methodology adopted in the present study

## Fracture Analysis from FMI Logs

Structure map on top of Basement (Fig. 4a) clearly reveals that the NE-SW rift trends swerves into E-W/ NW-SE due to the presence of Dharwarian and Cauvery shear zone along this area, which is the reason for generation of different fractures. Available FMI logs of drilled wells were utilized for the study.

The oil wells A & B show dominantly E-W & NW-SE trending fractures while the dry well E contains mainly NE-SW fractures (Fig. 4b). The fractures identified from the FMI logs of 4 wells were classified them into 3 major classes viz., E-W, NWSE and NESW sets (Fig. 4c). This classification is used to drive the seismic directional trends and finally populate the different fracture sets in the fracture model.

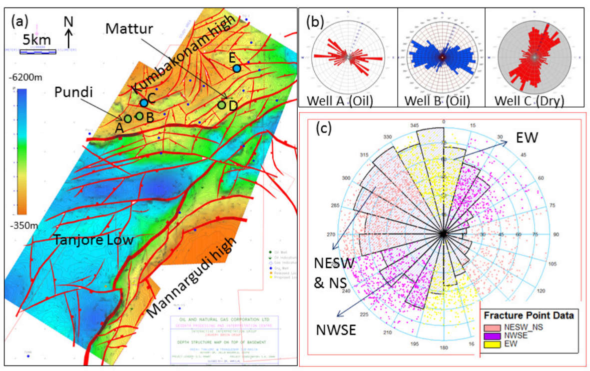


Fig.4: (a) structure map on top of Basement. (b) Strike Rosette of fractures in FMI logs 3 wells. (c) FMI fracture classification of 5 wells into 3 classes in stereoplot (poles to fracture planes).

### 1D- Stress & Strain Analysis

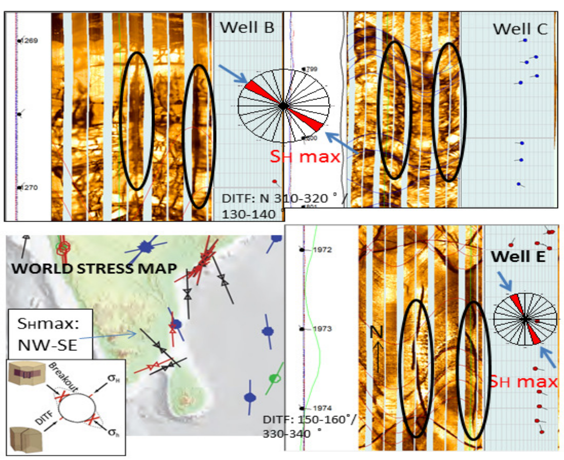


Fig.5: Drilling Induced Tensile failures observed in wells B, C and E suggesting the NW-SE trending SHmax in this region. This is also supported by World Stress Map.

The presence of DITF (Drilling Induced Tensile failure) in well B (at 1269.5m) & C (at 1790m) trending N310-320° and in well E (at 1973m), it is trending N 330°, suggesting that SHmax orientation is NW-SE (Fig. 5). It is also corroborated by literature (Fig. 5: World stress map by Heidbach et al., 2016; Chatterjee & Mukhopadhyay, 2002).

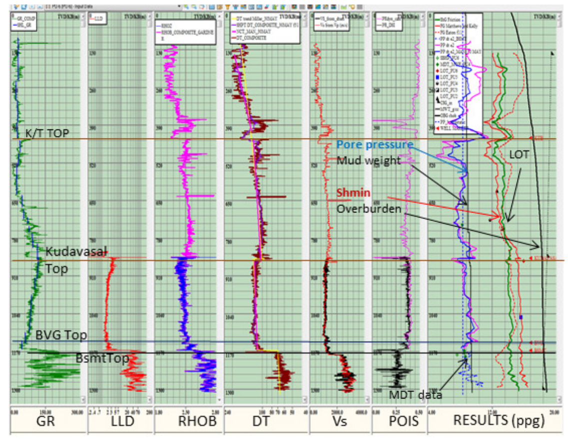


Fig.6: 1D- stress analysis in well B.

Stress magnitudes were estimated using standard practices (compiled in Zoback, 2007) for the 3 wells which were having FMI and DSI logs. Overburden (vertical stress, Sv) was estimated from density logs; Pore pressure from Eaton (1975) method (calibrated with MDT data), Fracture pressure from Mathews_Kelly (1967) (calibrated with LOT data), Shmin from Eaton Poisson Ratio method & Mohr-Coloumb failure method and SHmax magnitude from Stress Polygon (Zoback et al., 1985) (Figs. 6 & 7).

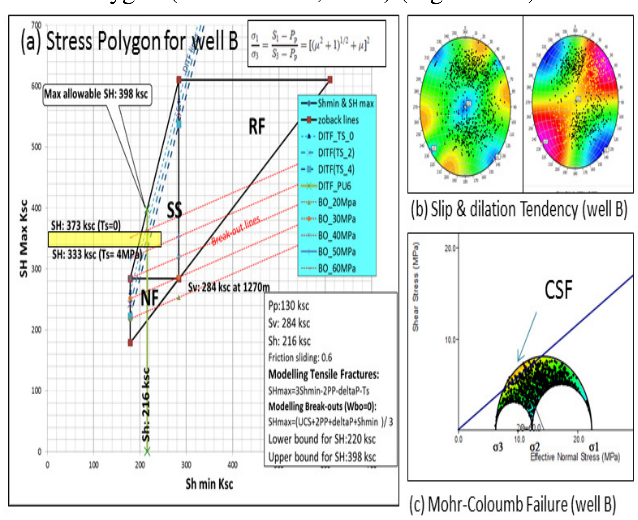


Fig.7: (a) Stress Polygon for well B. (b) Slip & dilation tendencies of fractures in FMI log of well B.(c) 3D Mohr circle of the fractures for identifying Critically Stressed Fractures (CSF).

The estimated average stress gradients 0.0105 MPa/m for pore pressure, 0.016 MPa/m for Shmin, 0.022 MPa/m for Sv and 0.032-0.04 MPa/m for SHmax. The stresses were applied on fractures 3D-Mohr circle (Fig. 7) & found that oil well B contain several critically stressed fractures in basement while the dry well C contain very few dilated fractures and lack of any critically stressed fractures (Fig. 8).

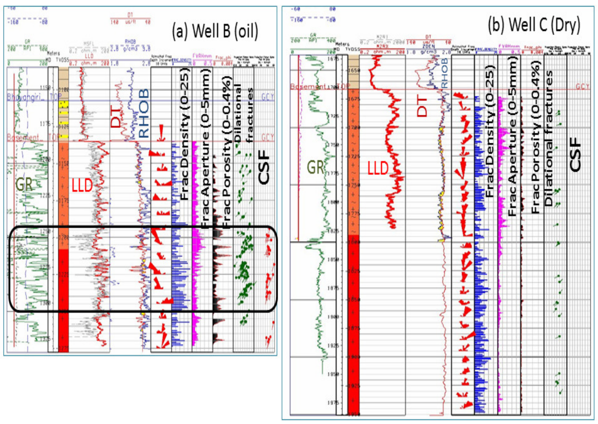


Fig.8: Fracture logs of (a) Well B (oil well) showing plenty of stress sensitive fractures and (b) Well C (dry well) having very few dilational and absence of Critically Stressed fractures (CSF).

## Seismic Attribute analysis

Structure cube volume (Fig. 9a) was initially utilized for fault mapping prior to basement mapping. The 3D seismic volume was cropped into a horizon probe (basement top to 400m below) by using mapped basement horizon, so that the structural features and seismic discontinuities could be enhanced along the highly dipping basement. This cube was conditioned by structural smoothening (dip guided, edge enhanced) to provide increased layer continuity without sacrificing vertical resolution and increased signal/noise ratio.

To see the discontinuities in the seismic data Amplitude invariant signal coherence analysis was done using variance (edge method) (Fig. 9b). This variance cube was used as input to generate the Ant track volumes with directional filters (following the fracture set classification using FMI data). The directional ant track results have clearly brought out the distribution of the sub-seismic features along classified directional trends (Fig. 10).

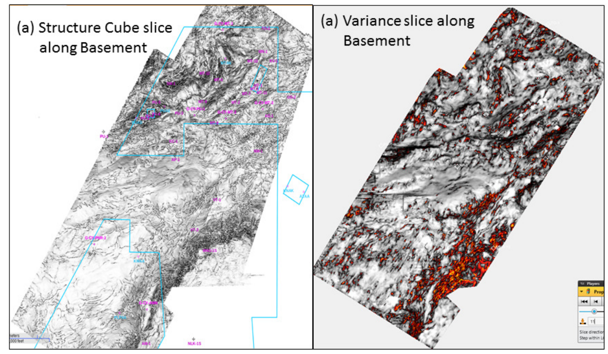


Fig. 9: (a) Structure Cube attribute and (b) variance attribute slices along basement top showing dominant fault and fractured zones.

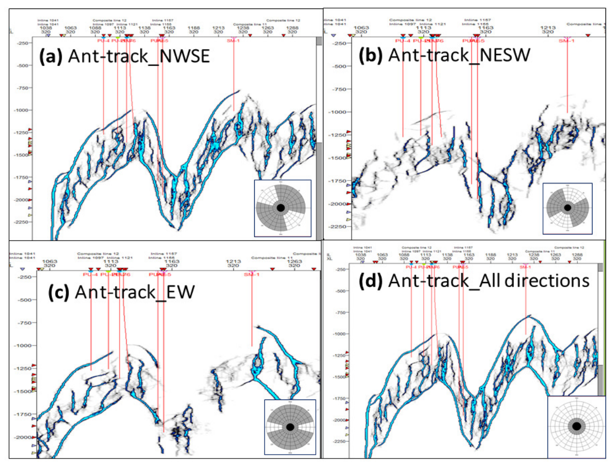


Fig. 10: Directional ant track fractures in NE-SW line along Pundi high in the horizon probe (basement top to 400m below).

## 3D Reservoir Grid

A geo-cellular model with cell size of 50mx50mx10m was built in the commercial software platform between the interpreted basement top and a mathematically derived surface at 400m below basement top. This was layered in 10m to preserve fracture intensity in finer resolution. Fracture intensity in the wells, derived from the FMI data was up-scaled into the grid as intensity property (Fig. 11). This intensity property was then populated to the entire grid geo-statistically, using data analysis (to determine the variogram parameters). The variogram was used to build the cumulative intensity property using Gaussian simulation, driven by the respective directional ant track-trends. Thus, the FMI fracture intensity and seismic intensity (from ant track) were integrated to build the final intensity for respective fracture sets for different directions and checked the results with the drilled wells in the area (fig. 12).

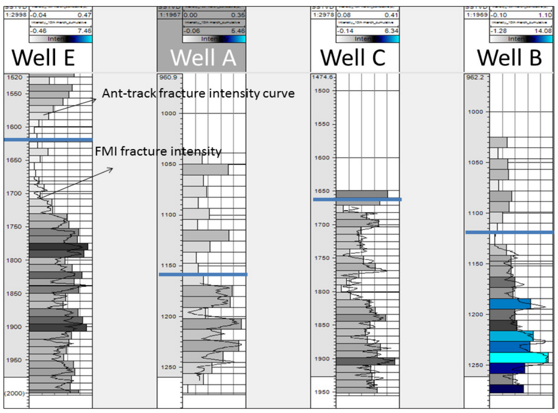


Fig. 11: Cumulative fracture intensity from seismic Ant-Track (all directions, histogram) calibrated with Upscaled Cumulative Fracture Intensity from FMI logs (Curves).

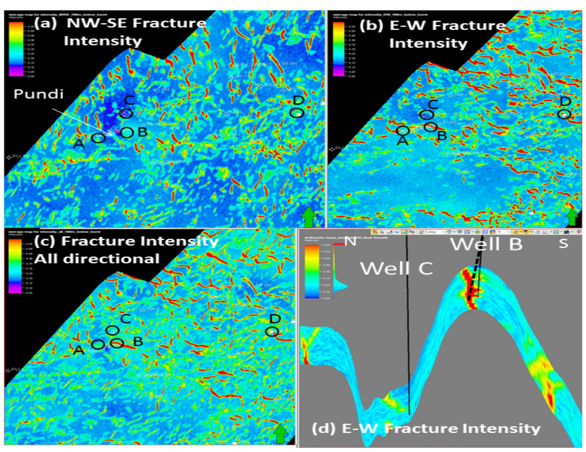


Fig. 12: Directional fracture intensity in study area (a-c). RC line along wells B (oil well) & C (dry) with E-W fracture intensity.

## Fracture Model

The cumulative fracture intensity property for the classified fracture sets was used to build the discrete fracture network (DFN) for each fracture set. The length, aperture and aspect ratio of the fractures were taken from the analyzed FMI data (Fig. 13).

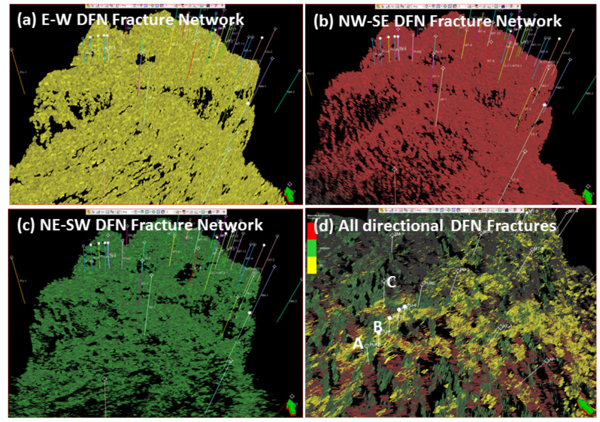


Fig.13: Directionally filtered DFN in the study area.

## Slip tendency analysis on DFN

Slip-tendency analysis is an effective geomechanical tool to make an assessment of stress condition, fault reactivation and fluid transmissive capacity of fractures. Slip-tendency is calculated by the ratio of shear stress to normal stresses acting on the fracture planes, which in turn depends on the orientation of the fracture in the given stress field. The fractures with high slip tendency (Critically stressed) play vital role in carrying hydrocarbons from longer distances.

The Slip tendency on 3D DFN fracture network was estimated from the 1D-regional stress gradients and found that the hydrocarbon bearing wells from basement lie in areas of high slip tendency (Wells A, B & D in Fig. 14). Four zones with high slip tendency have been identified (along with merits of structure map and fracture intensity)viz., 1) along the western flanks of Mannargudi high, 2) on the north of the study area, 3) on the fault closure lying east of well D and 4) on a intragrabenal high within Tanjore Low (yellow ellipses in fig. 14). However further study of cap rock is required for the zones 3 & 4, which lie on grabenal area, as synrift sediments rests over basement.

## Conclusions

The interpretation of FMI logs reveals that major fractures in this region are NE-SW (rift trend), NW-SE (Dharwarian cross-trend) and E-W/WNW-ESE (Cauvery shear zone). Bore-hole failures and wireline logs were utilized to deduce stress orientation (SHmax: NW-SE in this area) and magnitudes, and inturn identified critically stressed fractures at drilled wells. The fractures trending between NW-SE to EW appear to be conductive and holding the hydrocarbons. Directionally filtered 3D DFN fracture models were generated and identified critically stressed fractures in 3D space. The adopted workflow can be beneficial for future basement exploration studies.

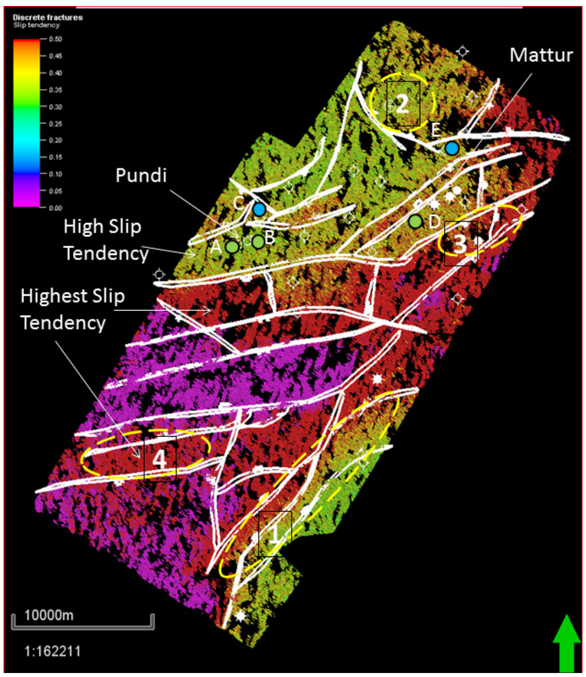


Fig.14: Slip Tendency Map of NW-SE DFN fracture network Critically Stressed fractured areas in warmer colours. Ellipses showing favourable locales for future exploration (numbered).

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