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Mitigating risk in drilling tight limestone reservoir by combining borehole images, critically stressed fractures and ant track methodology --- a case study from Vindhyan Basin.

Extended Abstract

Abstract:

Vindhyan basin consists of shallow marine sedimentary rocks pertaining to late Paleo-Neoproterozoic age. The basin is represented by two sectors; Chambal valley in the west and Son valley in the east. Two distinct depositional cycles, the Lower and the Upper Vindhyan are seen in this basin. The main exploration target is the Rohtas Limestone in Lower Vindhyan where significant gas presence has been discovered.

A number of vertical wells have been drilled in this area targeting Rohtas formation. Gas has been encountered in this formation, but commercial quantity has so far eluded. The formation is tight ($\Phi \approx 4\%$), but gas presence is established by production testing and during drilling. The gas occurrence coincides with presence of fractures in the image logs, which are acting both as storage and conduits. Fluid flow in these fractures is governed by the orientation of the fractures, which are dependent on stress state during their time of origin. The major trend of the fractures from the image log is found to be NE-SW and NW-SE. Few of these may be critically stressed under present day situations.

Detailed Geomechanical studies have been carried out in this area. Results from image log analysis and geomechanical studies are combined to assess the potential slip of each fracture. Effective normal stress and shear stress have been calculated. Mohr-Coulomb criterion has been applied to segregate the critically stressed fractures (CSF).

Both CSFs and image logs are concerned with near well bore events. To confirm the presence of fractures away from the well bore, Ant Track technology was applied. Ant Track extracts fractures and faults in 3D space by picking up discontinuities. The major trend of fractures obtained from Ant Track is similar to those obtained from image logs. Combining results from image logs, CSF analysis and Ant Track technology deviated wells have been proposed and drilled in this area. More gas has been encountered in MLU during drilling and more fractures seen on image logs as envisaged in the pre drill model, reducing risk and increasing the confidence in exploring this area.

These paper high lights the key results of near well bore fractures analysis from image logs, CSF analysis and fracture analysis from Ant Track methodology and how these results have been exploited to reduce risk and increase confidence in drilling new wells.

Introduction:

Vindhyan basin consists of shallow marine sedimentary rocks pertaining to late Paleo-Neoproterozoic age. The basin is represented by two sectors; Chambal valley in the west and Son valley in the east. Two distinct depositional cycles, the Lower and the Upper Vindhyan are seen in this basin. The main exploration target is the Rohtas Limestone in Lower Vindhyan where significant gas presence has been discovered
In Jabera, Nohta and Damoh area of Vindhyan basin vertical wells have been drilled and full set of logs including the image logs have been recorded. Conventional logs have not been very helpful in identifying the hydrocarbon accumulations. Gas shows have been observed during drilling in the MLU. A close look at the image logs reveals that the gas intervals are associated with fracture presence. SEM study of the cored interval also confirms the presence of fractures. Upon testing these fractured intervals gas presence was established. However, this gas was not of commercial quantity.

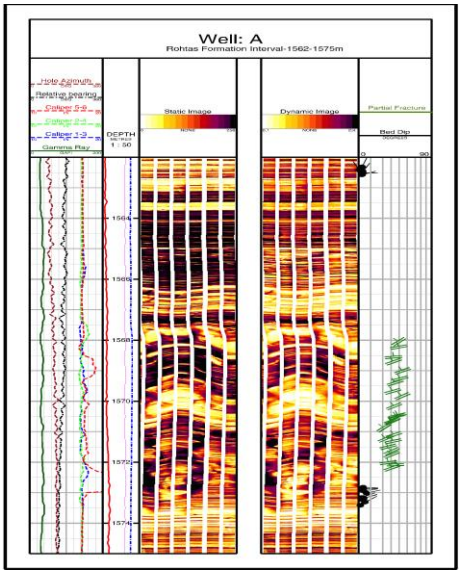
Image logs interpretation:

A number of wells have been drilled as vertical wells in this area. Image log data have been acquired in almost all he wells. Two representative wells, Well A and Well B have been chosen for this study. Image data for these wells has been processed and interpreted and reveals the presence of fractures within the Rohtas formation.

In Well A, the processed logs suggest that the fractures here are mainly partial fractures. These fractures are having dip between 50 to 85 degrees in the NW direction (Fig 1). Stereonet plot corroborates the dip and direction of the fractures. Since the strike direction is orthogonal to the dip direction, the strike direction of these fractures comes out to be NE-SW.

The maximum concentration of the fractures is seen in the interval X565-X585m on the processed logs. This interval coincides with the interval where gas shows were encountered during drilling. MLU had recorded a maximum T.G. of 10% in this interval.

For Well B, the maximum concentration of fractures as seen in processed logs is in the interval X616-X710m. The fractures are diagnosed as both open and partial (Fig 2). The trends of the dips are in NW and SW direction which suggests the strike direction as NE-SW and NW-SE. (Fig 3b). A T.G. ranging from 11% to 26.7% has been observed in this interval during drilling.



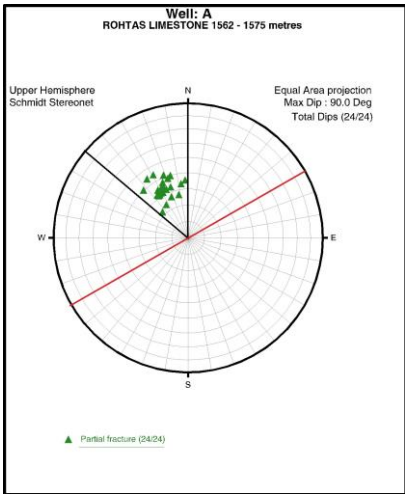


Fig 1. (Left) Fractures picked from Image logs for Well A. These are mostly partial fractures and gas shows have been encountered in the zone of maximum concentration of fractures. (Right) Stereonet diagram showing strike direction of fractures as NE-SW

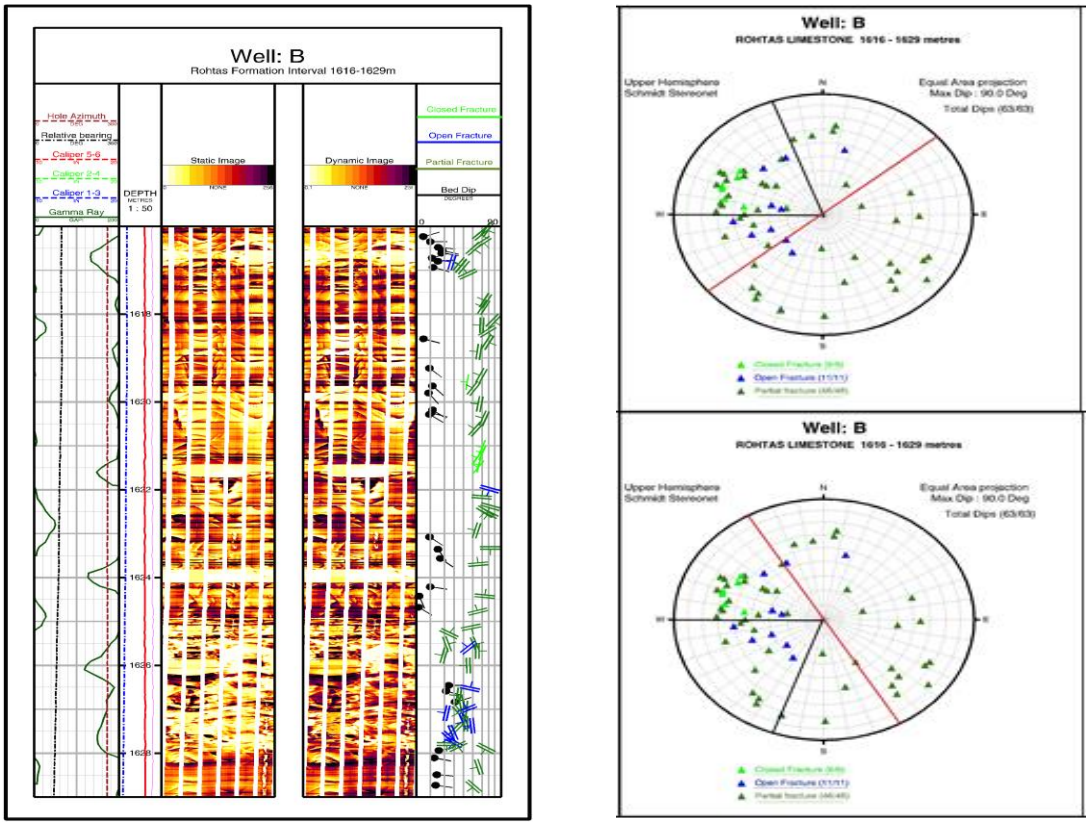


Fig2. (Left) both open and partial fractures are seen on image logs in Well B. This interval had produced gas on testing. (Right) NE-SW and NW-SE is the major trend of fractures as seen in stereonet plot for Well B.

Critically Stressed Fractures (CSF) study:

Fluid flow in low permeability rocks is governed by the natural fractures. The orientation of the natural fractures depends on the stress state during the time of their origin. Few of these are critically stressed under present day stress condition and govern the fluid flow. According to the critically stressed fault hypothesis, fractures that are mechanically alive are hydraulically alive too and vice versa (Dr M. Zoback, Reservoir Geomechanics). A CSF analysis depicts natural fractures that are critically stressed under present day stress regime

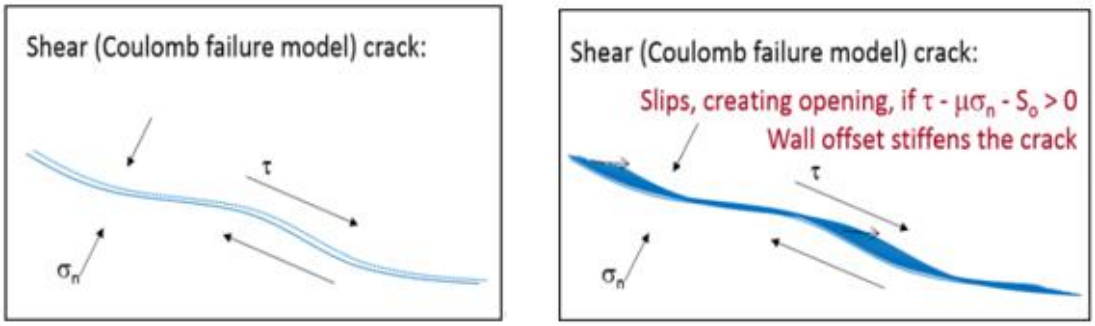


Fig.3. Concept of critically stressed fractures analysis. (Left) Fractures at initial in-situ stress and pore pressure. (Right) Fractures can be made critically stressed by increasing injection pressure that can cause shear slip fractures.

To quantify the potential slip of each fracture under in situ stress condition fractures from image logs and parameters from geomechanical modeling are combined. Effective normal stress (σn) and shear stress (τ) are calculated at each fracture plane. (Fig 3.) Mohr- Coulomb failure criterion predicts the stress state of individual fracture and clearly segregates the critically stressed fractures (white dots) above the failure envelope. (Fig 4.)

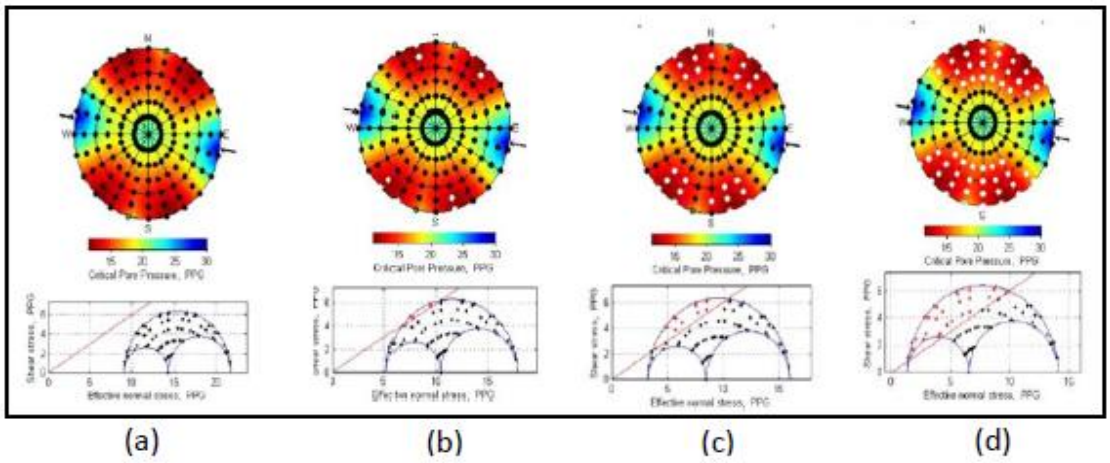


Fig 4. CSF simulation results for all possible fractures presented in stereo plot and Mohr circle. (a) No injection (initial condition), (b) injection pressure 1000 psi,(c) injection pressure 1500psiand (d) injection pressure 2000psi

CSFs are mainly concern with near well bore events. To see fractures away from the well bore, which have a major influence on the flow of fluids Ant Track methodology has been employed.

Ant Track Methodology:

Ant Track technology extracts probable faults and fractures from seismic data. Ant track methodology is different from conventional methods in the sense that it picks up minor variances in seismic data continuity. It consists of four major steps:

a) Conditioning of the seismic data by reducing signal to noise ratio.
b) Enhancing spatial discontinuities (generating fault attributes, edge detection etc.)
c) Generating Ant track volume which significantly improves the fault attributes (by suppressing fault attributes and remains of non – faulting events)
d) Fault modeling.

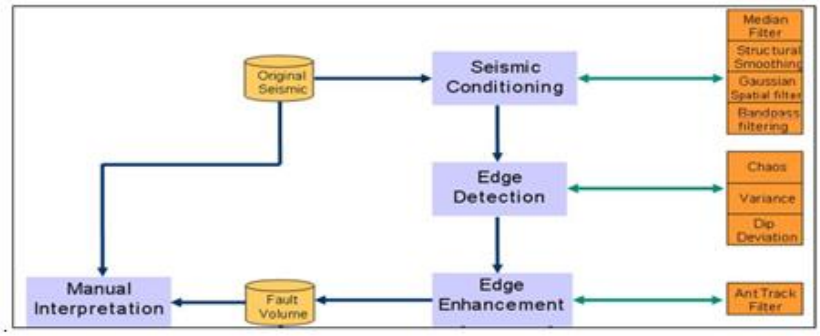


Fig. 5. Work flow for Ant Tracking

Ant Track technology extracts probable faults and fractures from seismic data by picking up the discontinuities in the seismic volume arising because of both faults and fractures. Faults can also be identified by a number of other attributes such as variance, positive and negative curvature, dip illumination, amplitude contrast etc. Faults thus generated by each of this method are superimposed on the Ant track volume. Filtering these faults what remains in the Ant track volume can be taken as fractures / micro fractures. (Fig. 6). It is seen that the fractures generated from Ant Track have similar orientation as those obtained from image logs.

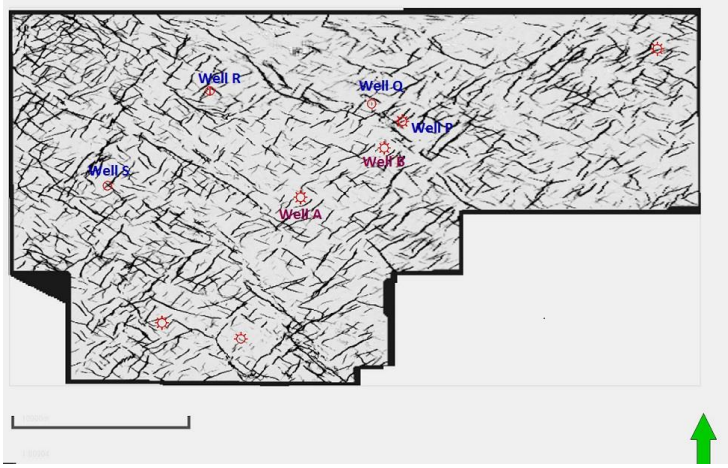


Fig. 6 Fractures generated from Ant track methodology with proposed wells (in blue colour)

To confirm the gas bearing potential of these fractures, four wells have been proposed in this area on the basis of the inputs from image logs, CSF analysis and the Ant track study. In order to maximize the production from each of these well, deviated wells have been planned. The defined trajectories have three main considerations:

It intercepts the maximum number of fractures

It sees the maximum number of critically stressed fractures

Due weightage is given to NE-SW and NW-SE trending fractures.

Based on the above analysis, four wells P, Q, R and S had been planned and drilled in this area (Fig 7). For the first time, deviated wells in Rohtas formation have been drilled keeping the deviation and the azimuth as per the model. The results have been encouraging as envisaged in the pre drill model. (Fig 8).

The drilled wells have shown encouraging results. As predicted in the pre drill model, the gas encountered in the MLU during drilling is significantly higher than that observed in the vertical wells. The image logs also show higher number of fractures (Fig 8).

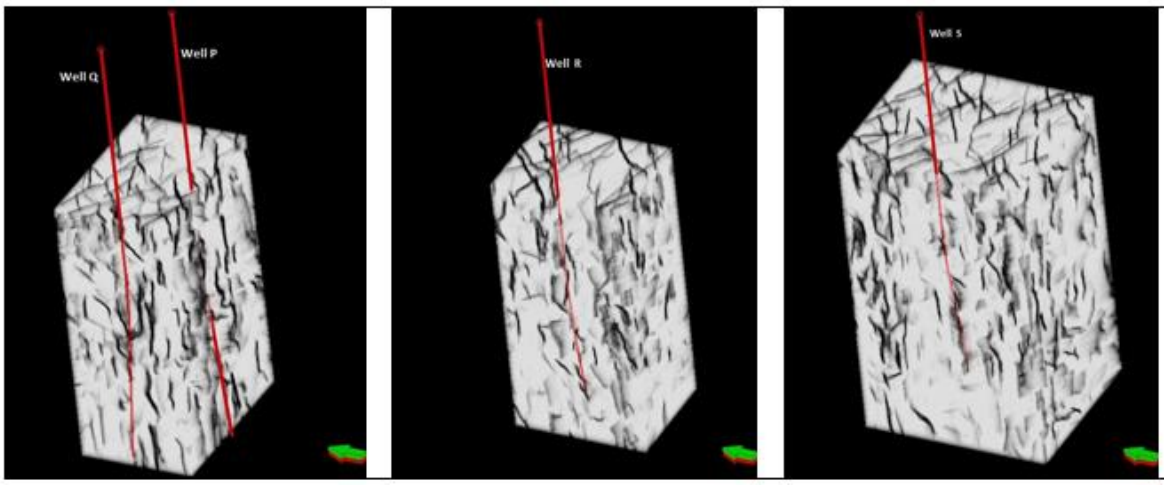


Fig 7. Trajectories of wells P, Q R and S in 3D Ant Track volume showing the intercepted fractures

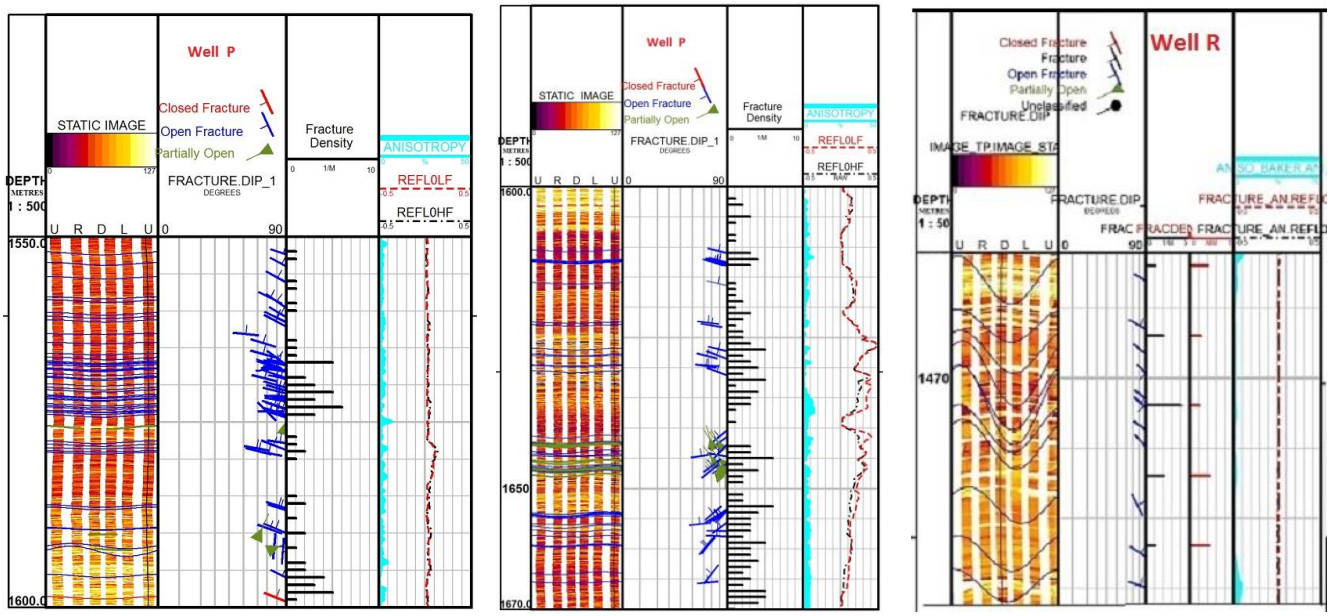


Fig 8. Actual fractures in Well P and Well R as seen on processed image logs

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Conclusions:

1. Image logs confirm the existence of fractures within Rohtas formation. Major trend of the fracture is NW-SE in Well A and NW-SE and NE-SW in Well B.
2. Fractures that are critically stressed under present day stress condition govern the fluid flow.
3. GMI reveals that strike slip stress regime exists in this area.
4. Ant Track technology visualizes and predicts fractures in the entire 3D volume. The major trend of the fractures near Well A and Well B is similar to that obtained from image logs.

5. Based on image logs, Ant track technology and CSF studies, deviated wells have been proposed for better exploitation of the area.
6. Combination of image log results, Ant track technology and CSF studies has drastically reduced the uncertainty in drilling new wells.

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