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Author **Pawan Dube , ONGC , India**

Co-Authors **Manoj Kumar, V L N Avadhani, P P Deo**

Fracture Characterization in Tight Fractured Limestones for exploitation strategy: A case study in Vindhyan Basin

Abstract

Fracture characterization is a big challenge for the geoscientists in sandstone and carbonate reservoirs, Even with the advancement of technical capabilities in the acquisition of surface and subsurface Geological data, it is still extremely difficult to understand, characterize, and predict the distribution of fractures in a field. Image logs can successfully be used to locate and to provide directional trends of fractures near the wellbore. However, capturing all the fractures in one well and to predict their flow behavior can still be a challenge. In this paper, a case study of a fractured carbonate reservoir will be presented. The field is located on Son Valley of Vindhyan Basin and 16 exploratory wells have been drilled so far, as a part of a concerted exploratory effort to explore the shallow gas discoveries, exploratory wells were drilled in the Nohta-Damoh-Jabera corridor of the PEL block during last few years. The reservoir rock has very low primary porosity and permeability, and the flow is through fractures only. Image data showed abundance of fractures with different orientation in the well bore but the well didn't flow from all the fractured zones. In this study, fracture attributes data from image logs along with the existing knowledge of regional stress orientation has been used to corroborate with the gas indication in the wells.

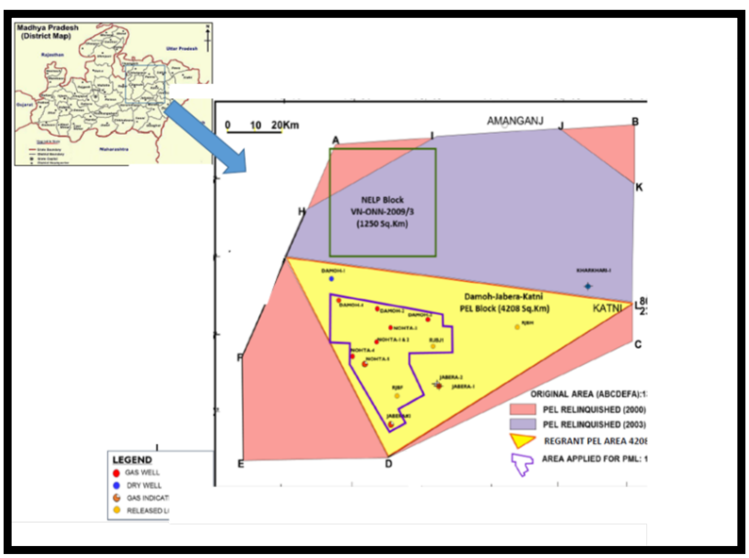
Introduction

Micro-resistivity borehole image logs can provide information about the fracture system in the subsurface. Fracture aperture which is one of the key parameters for assessment of fluid flow in naturally fractured reservoirs can be estimated from borehole image data. Micro-resistivity imaging data has been recorded in wells; which were used for fracture characterization in area under study.

Field Studies Location

The study area falls in the Nohta-Damoh-Jabera applied PML area, in the erstwhile Damoh-Jabera-Katni nomination PEL Block. Damoh-Jabera-Katni nomination PEL Block in Son Valley, Vindhyan Basin was awarded to ONGC in 1997. As depicted in the figure-1 Nohta-Damoh-Jabera area, measuring 1150 Km2 has been applied for PML by ONGC with a firm minimum work program. An area of 15 Km2 around wells Nohta-A and Nohta-B, within the applied PML, has been identified as a marginal field and is under bidding for appraisal/development.

Vindhyan succession represents a thick sedimentary pile, about 6000m belonging to Meso–Neoproterozoic age. The entire succession belongs to two distinct depositional cycles. The older one dominantly calcareous and argillaceous with volcano clastics, referred to as Semri or Lower Vindhyan. The younger cycle, is dominantly siliciclastic with minor proportion of carbonates, commonly known as Upper Vindhyan comprising of Kaimur, Rewa and Bhander Subgroups. The upper Vindhyan succession unconformably overlies the lower Vindhyans. The stratigraphic succession of Vindhyan Supergroup is presented in Table-1. Present study is focused on Rohtas limestone which is part of Lower Vindhyan group. Rohtas



formation is represented by alternate limestone and shale sequence and consists of various litho-units.
Figure 1: Location map of area under study.

Upper Vindhyan	
Unconformity	
Lower Vindhyan	Rohtas Limestone
	Basuhari Glauconitic Sandstone/Rampur Shale
	Mohana (Fawn) Limestone
	Chorhat Sandstone
	Charkaria Shale/Koldaha Shale
	Jardepahar Porcellanite
	Kajrahat Formation
	Arangi Formation
	Deoland Formation
Unconformity	
Basement	Bijawar/Mahakoshal Group/Bundelkhand

Table 1: Generalized stratigraphy of the Son valley sector, Vindhyan basin; Details of only Lower Vindhyans is given.

Fracture Type in Rohtas Limestone Formation

The fractures encountered in Rohtas formation are not classical natural fractures, majority of fractures are either re-crystalized or reworked (same is also seen in conventional core recovered during drilling; shown in Figure-2). Only few among high conductive features does cross full well bore i.e. seen on all the pads of Micro-resistivity Image logs, majority of them are encountered on only two or three pads of image log. In first look one may ignore them considering as natural fractures. While picking fractures from Image log, the fractures were picked optimistically i.e. maximum number of fractures were picked as possible. This was done so that any probable fracture zone is not left out; since only open fractures contributes to fluid flow hence these are classified and kept different set while fracture picking from image logs and used for fracture aperture computation.

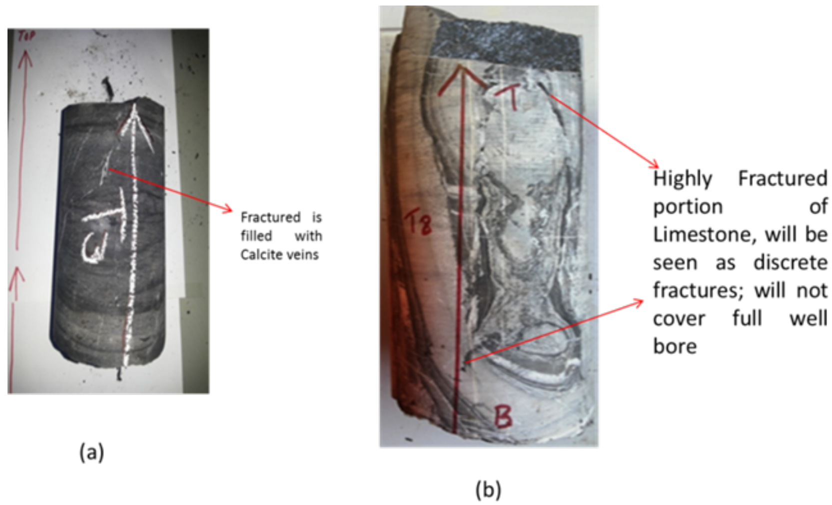


Figure 2: Two core plugs with fractures; (a) Filled fracture with Calcite Mineral and (b) High angled discrete fracture.

Fracture Stress Orientation

Understanding natural fracture orientation with respect to present day stress play key role in assessment of fluid flow behavior along natural fractures. Flow can occur only along pre-existing fractures oriented in direction of maximum horizontal stress in the host-rock. The complex fracture network will have a range of orientations and will exist within a complex stress regime. In present case fractures are plotted on rose diagram(given in figure-3) to know their orientation with respect to present day stress; Present day stress direction is determined using breakouts and drilling induced fractures on micro-resistivity image logs.

As inferred from the Figure-3; there are two major trends in fracture orientation i.e. NE-SW and NW-SE. Majority of breakouts seen on image logs are aligned 110±10 deg with respect to North i.e. the direction of present day maximum horizontal stress is NE-SW.

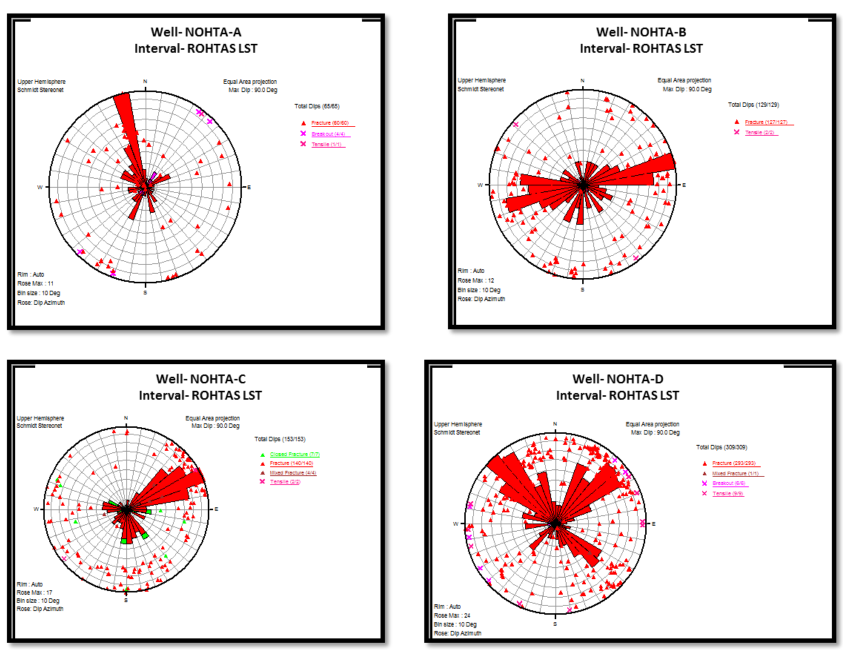


Figure 3: Fracture Orientation in four wells of the area under study.

Fracture Density and Aperture

Fracture aperture, which refers to the opening size of a fracture, is a critical parameter controlling rock mass permeability. Moreover, distribution of permeability within Rohtas limestone is totally dependent on the fracture occurrences. In water based mud environment, borehole imaging tools are able to identify both location and aperture size of the intersected fractures due to enhanced conductivity in the fractured region. The size of the regions of enhanced conductivity associated with fractures is proportional to;

1. Their actual width.
2. The resistivity contrast between fracture fill and surrounding host rock.
3. The geometry of fracture at borehole wall and
4. The electrode button dimension

In 1990, Luthi and Souhaité provided a method to estimate fracture apertures from electrical borehole image logs. This method demonstrate that the borehole imaging tools respond to the fractures by an amount of excess current compared to the background rock response as the tool crosses the fracture. Further it was shown that the integration of the excess current could be directly related to the width of the fracture through equation;

$$W=c.A.R^{b}_{m}.R_{xo}^{1-b}$$

The relationship between fracture width **W** (in mm), formation resistivity $\mathbf{R_{xo}}$, mud resistivity $\mathbf{R_m}$, and the additional current flow **A** caused by the presence of the fracture. **A** is the additional current which can be injected into the formation divided by the voltage, integrated along a line perpendicular across the fracture trace. Coefficient c and exponent b are obtained numerically from forward modeling.

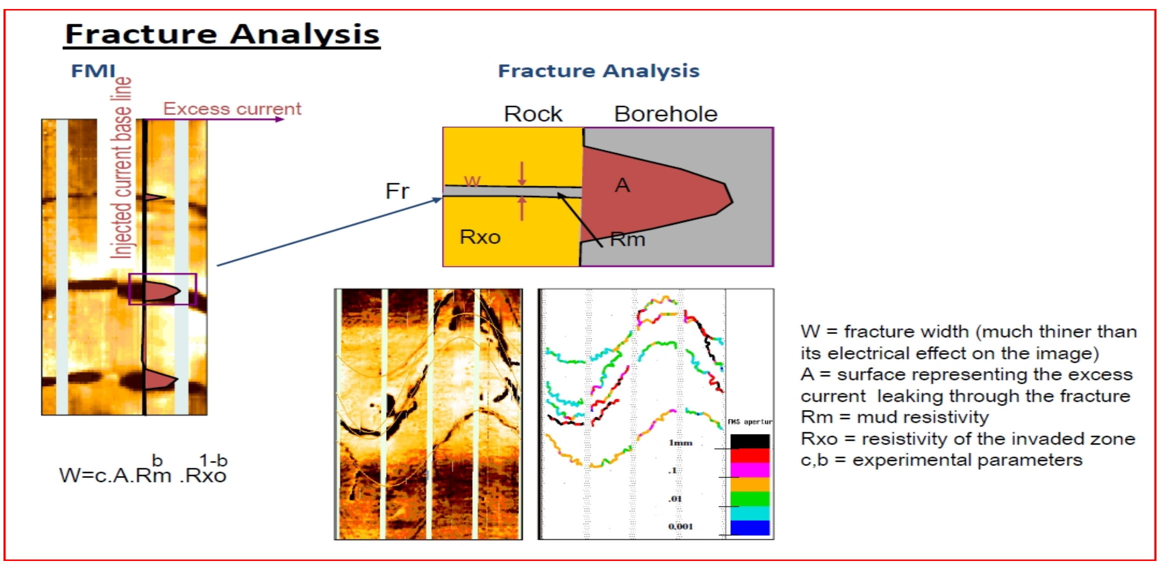


Figure 4: Fracture aperture computation using electrical image logs.

While it is a great innovative method, the results should not be regarded as absolute values due to the large uncertainties related to the modeling assumptions. In present case, the parameters **"b=1.2"** and **"c=0.7"** are taken so that the computed fracture aperture can have a near realistic value.

Fracture attribute in interval XX90-XY80m of well DMOH-B is plotted in Figure-5. Tracks in figure-5(a) are numbered from Track-1 to 9 represents GR, Depth, Resistivity, Density-Neutron, Dynamic Image, Fracture dip-azimuth, Fracture Density Fracture Aperture and gas shows during drilling respectively. Figure-5(b) consists of fracture aperture distribution in logarthamic scale from 0.001 mm to 10 mm and figure-5(c) is rose diagram of fracture azimuth in this interval. Despite of excellent fracture aperture and good fracture density in interval XY32-XY79 m there is no gas show during drilling this interval. Interval

XY52-XY61.5 m, XY44.5-XY49.0 m and XY32.5-XY40.0 m was perforated @ 20 SPM, after applying Nitrogen two times there was no gas flow during production testing.

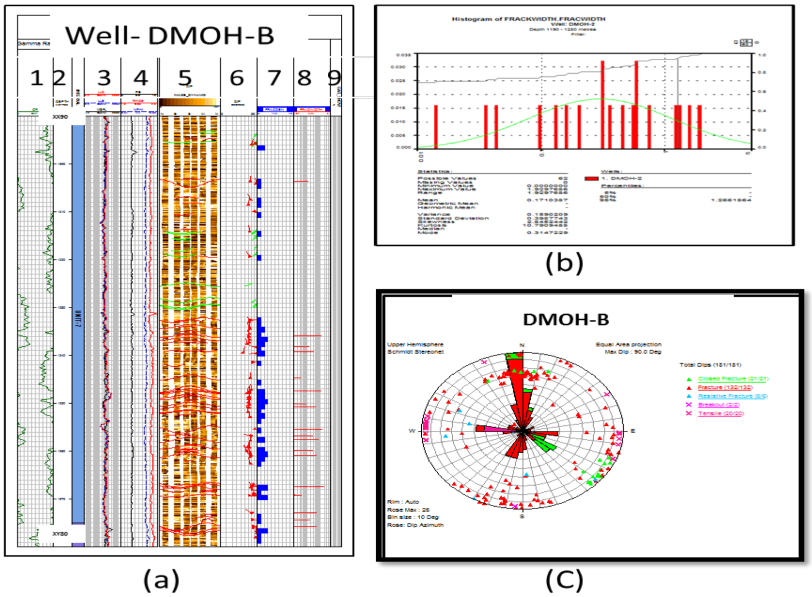


Figure 5: Fracture attributes in well DMOH-B in interval XX90-XY80 m; (a) Fracture attributes, (b) Fracture aperture distribution and (c) Fracture orientation.

Interval XY00-XY42 m of well NOHTA-C is given in figure-6, this interval is fractured with reasonably good fractures of average fracture density 1.5 fractures/meter. Fracture aperture in this interval is varying from 0.016 mm to 0.40 mm and mean fracture aperture is 0.12 mm. Statistically 95% fractures have fracture aperture of 0.27 mm. Along with reasonably good fracture density and aperture; most of the fractures are aligned in the direction of present day maximum stress as inferred from figure-6(c). This interval contributed formation gas during drilling. Interval XY29-XY24 m, XY21-XY16m were tested, initial flare height was 2 feet and improved to 4 feet after acid job.

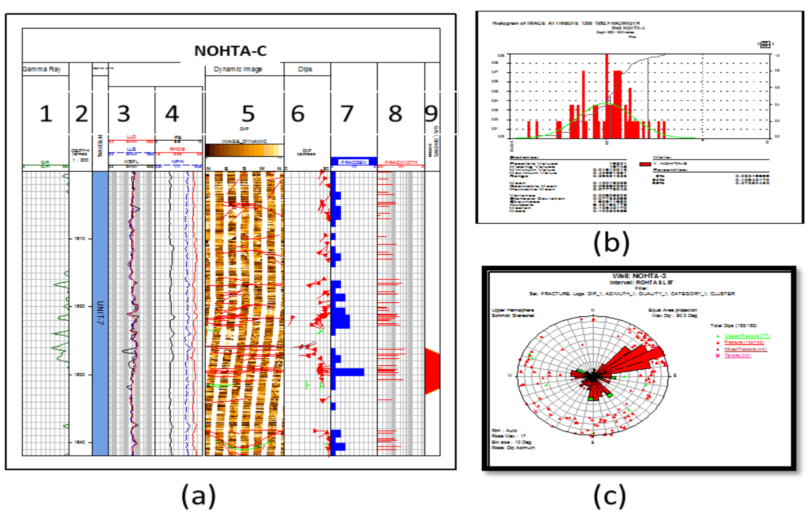


Figure 6: Fracture attributes in well NOHTA-C in interval XY00-XY42 m; (a) Fracture attributes, (b) Fracture aperture distribution and (c) Fracture orientation.

Conclusion

Fracture type (open, partially open or closed), orientation, density and aperture are most essential characters to decide its flowing character. These attributes can be computed using micro-resistivity imagers. In the current study, fracture orientation, dip, density of open/ partially open fractures and aperture of open fractures have been computed. Fracture attribute data interpretation of all the wells infers that mean fracture aperture of fractures in Rohtas limestone section are 0.1208 mm. Individual well analysis infers that in general the zones with fracture density 4 fractures/meter and fracture aperture grater 0.10 mm with sufficient interval (of the order 5 meters) are only gas contributors. Fracture aperture distribution of all the wells under study is given in figure-7.

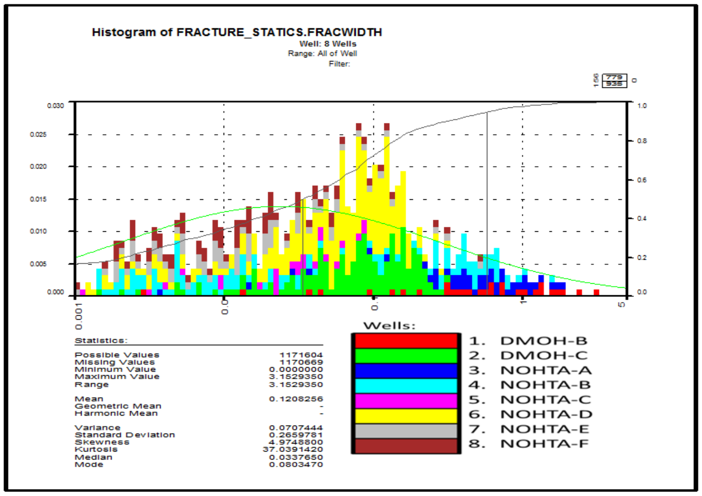


Figure 7: Distribution of fracture aperture in area under study.

Acknowledgement

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