

A synergistic approach for Petrophysical evaluation of fractured basement. A case study in Basement of Cauvery basin - India

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Keywords

DIFs, SHmax, PLT, Resistivity Image logs, Stoneley, Shear wave.

Summary

Disparity in production rate of the wells from fractured basement within the same structure has been explained by integrating resistivity image logs and advanced sonic measurements with production logging. This synergistic approach helped to understand fractured basement, fracture network and its apertures, dependency of fracture producibility to principle stress direction. These study summaries that, existences of fractures which are in line with SHmax are directly related to the productivity of fractured basement.

Introduction

Natural fractures and faults are the primary conduits for hydrocarbon migration and production in many reservoirs, especially in basement rocks. Basement exploration has acquired a much more focused, systematic tone in recent times, following several new oil and gas discoveries in this complex reservoir type. In this paper, authors are proposing a comprehensive methodology for integrating various open hole logs including image logs, advanced sonic logs and production logs to better evaluate the reservoir potential as well as its producibility. Log analysis and formation evaluation of basement reservoirs are entirely different from that of its sedimentary counterparts. All the conventional interpretation techniques are developed for sedimentary rocks only and these methods cannot be extended to basement since the hydrocarbon accumulation and migration in basement is mainly through fractures and the productivity potential for each fracture can vary significantly. The objective of the following study was to characterize fractured basement encountered in wells of Madanam field, based on logs particularly new generation logs like resistivity image logs and advanced sonic logs in addition to production log data and to identify and prioritize more prospective zones.

Geological back ground

Cauvery basin is part of the pericratonic rift system on the southern edge of Indian continent. It extends from Pondicherry in the north to Turicorin in south. Configuration of Cauvery Basin is ideally

suited for charging of the basement highs, having a series of elongated basement high juxtaposed on both sides by thick columns of sedimentary strata with proven source rock potential.

The study area, Madanam field in Cauvery basin, is a classic example of fractured granitic basement which is producing oil & gas in considerably good rates. The structure is situated in Ariyalur-Pondicherry sub-basin, is on the margins of Madanam horst. The axis of the horst is NW-SE direction in eastern part and changes to NE-SW in central part. The cross-faulted horst block has a favorable locale for younger NW – SE cross trending faults creating entrapment within the Basement and younger tertiary sequences. A geological cross section across the Ariyalur-Pondicherry sub basin through Madanam high illustrates the source and possible migration path. A series of longitudinal faults trending NE-SW are the main extensional faults associated with the Syn-rift regime of basin formation and another orthogonal fault system is trending NW-SE dissecting the older NE-SW trending fault.

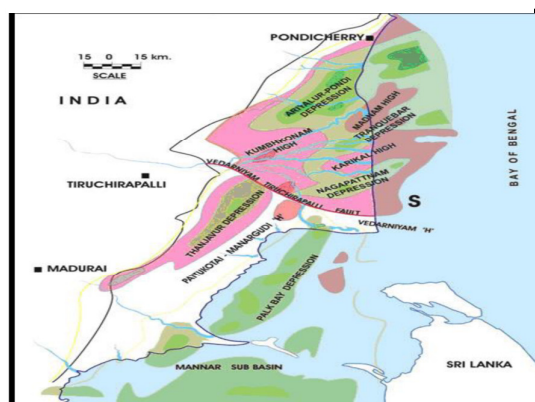


Figure 1: Geological cross section through Ariyalur-Pondicherry sub basin.

Methodology

Integration of basic log suits with resistivity images, dipole shear sonic data & Stoneley permeability for characterizing the fracture network system in the basement rocks. Image logs provides high resolution images, can be used for detailed assessment of the fractures in the basement such as type of fractures, dip & azimuth and other attributes like fracture apertures, fracture porosity. Additionally analysis of other events, drilling induced fractures (DIFs) and breakout will help us

understand in-situ principle horizontal stress (SHmax) orientation which plays major role in fracture driven production from the basement.

Advanced sonic logs are sensitive to the presence of fractures in the basement which differentiate permeable and clay filled fractures. Stoneley wave sonic logs are commonly used for calculation of stoneley derived permeability. In fractured basement, from dipole shear sonic data, fast shear azimuth will be along fractures strike direction.

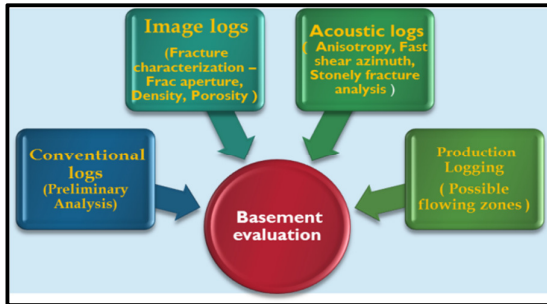


Fig-2: Methodology in Basement evaluation

Combining information from the image and advanced acoustic logs, the open fractured zones shows high fracture apertures/porosity from image logs and good stoneley reflection coefficient. In final steps, production logs are recorded in the basement to ascertain producibility of the basement layers. Together, a detailed analysis of the fracture parameters versus production data could be carried out to identify a variable or a set of variables such as dip, azimuth, aperture, fracture porosity which is controlling hydrocarbon flow. Geological, geo-mechanical reasons can then be attributed to understand the reasons for producibility of one fracture sets over other (e.g. critically stressed fractures).

Analysis

In this field, so far, 9 wells were drilled with an objective to produce oil from basement. On the basis of availability of log data, two wells (Well-A&B) were selected for this analysis and both wells penetrated considerable thickness in the basement section. Continuous hydrocarbon shows were observed during drilling of the basement. Well-A penetrated ~ 300 m fractured basement which produced Oil @ 116 m³/d, Gas @ 9000 m³/d. Well-B is drilled ~ 500 m through basement and produced Oil @ ~ 30 m³/d, Gas @ 6000 m³/d. Both wells penetrated same reservoir having same reservoir pressure (1.36 MWE) with same type of slotted casing completion. Log motifs are displayed in Fig-3. However, the difference in production rate was turned out to be a surprising with such a prolific basement reservoir. It was believed that,

fracture network system may be playing vital role, so logs were analyzed to find out the factors aiding for the productivity in fractured basement reservoir. Conventional logs, Image logs and Shear sonic were recorded to understand the basement and fracture network. Regional stress map data has been taken into consideration while analyzing in-situ stress direction which shows SHmax direction is NE-SW direction. PLT logs were recorded for identification of producing intervals in basement section.

Well A: Resistivity image log shows that, the basement encountered is highly fractured and presence of parallel high angle fractures whereas other interval in basement shows that either a complex pattern of non-parallel or crisscrossing fractures. It is found that, conductive fractures identified in the basement section are showing mainly two sets of strike direction. One is along NE-SW direction and second one is along the direction of NW-SE direction with average dip angle in the range of 45 -70 deg. One set (NE-SW fractures) are along regional in-situ maximum stress (SHmax) direction whereas other set (NW-SE) are orthogonal to SHmax. The histograms of fracture attributes of both set of fractures (NE-SW & NW-SE) shows NE-SW strike conductive fractures are having higher values of fracture aperture than NW-SE strike fracture (Fig-4). In view of these high values of fracture attributes, it can be inferred that NE-SW strike fractures are having better communication to the well bore than other set of fractures. Across many intervals in basement section, both set of fractures NE-SW & NW-SE can be seen simultaneously. Hence, it is difficult to differentiate the productivity of these set of fractures separately.

From the advanced acoustic measurements, fast shear azimuth is dominantly along NE-SW direction which infers dominant fracture strike direction. NE-SW strike fractures identified from image logs are showing good stoneley reflectivity index which are also indicating, fracture opening and its extension.

From the Production logging, it observed that, major hydrocarbon production from three zones (A, B &C). In these zones, image logs shows dominant fracture's strike is in NE-SW direction. Furthermore, stoneley fracture analysis confirms these three zones Zone-A, B&C are having better open fractures. In well-A, NE-SW strike fracture in basement section, which is along the SHmax, are having better fracture attributes (aperture, porosity) values than the other set (NW-SE) fractures. Stoneley reflectivity index also confirms NE-SW fractures are having better fracture opening than other set.

Well No-B: Presence of both high angle fractures and crisscross fractures are seen in resistivity image logs. Dominantly NW-SE strike fractures are seen in Image log with average dip angle in the range of 40 -70 deg. That means, conductive fractures identified are not in line with direction of regional in-situ SHmax. The histograms of fracture attributes identified fractures shows lesser values compared to Well-A(Fig-5). From the advanced acoustic measurements, fast shear azimuth is dominantly along NW-SE direction which implies dominant fracture plane direction. Against identified fractures in the basement section, stoneley wave analysis also shows less reflectivity index. It endorses that, conductive fractures identified from image logs are having lesser opening and extension than fractures identified in well -A. In Well-B, the identified fractures are having strike direction in NW-SE which are not in line with regional in-situ principle horizontal stress.

Conclusion

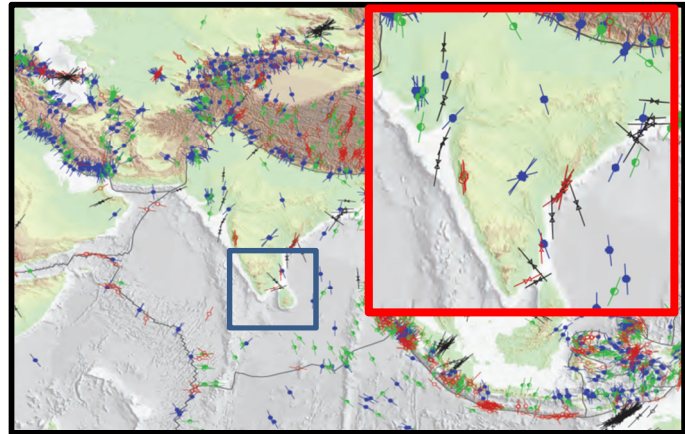
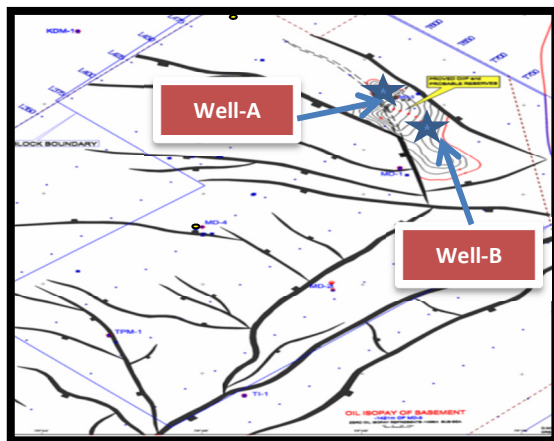
Both analysed wells are drilled in the same structure and penetrated same basement reservoir but with different production rate. From the fractured basement characterization using image logs, advanced acoustic measurements and PLT logs, it is evident that, strike plane of fractures identified in Well no-A are in line with regional in-situ principle stress direction where as in Well no-B, strike plane of fractures are not in line with SHmax. Those fractures which are coherence with direction of SHmax, are having better fracture apertures, porosity and likely to be hydraulically active. Existences of such fractures in basement section are directly related the productivity fractured basement. In summary, this highlights the fact that the productivity is not only controlled by fracture aperture but its orientation, local maximum horizontal stress direction and degree of connectedness.

References:

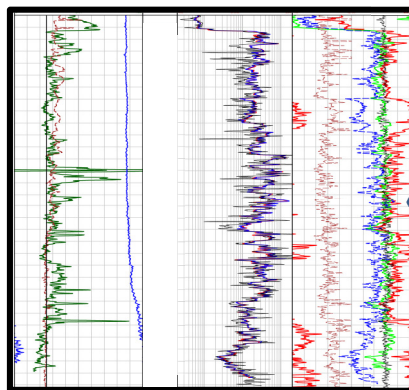
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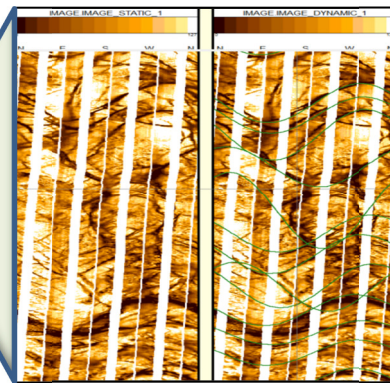
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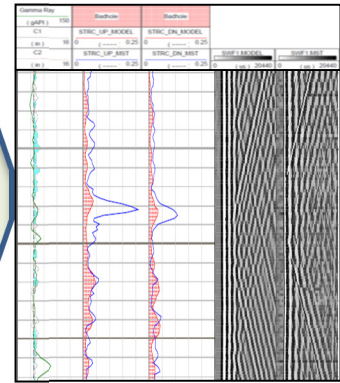
Structure map & Word Stress



Conventional Log

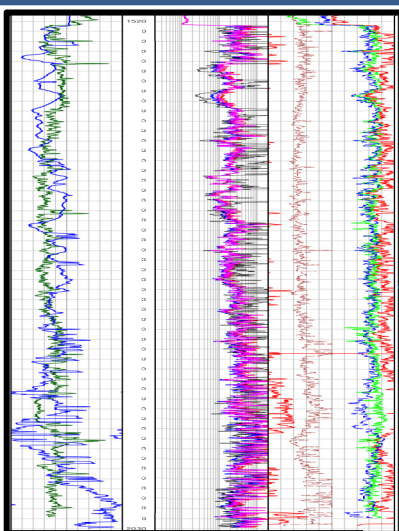


Resistivity Image Log

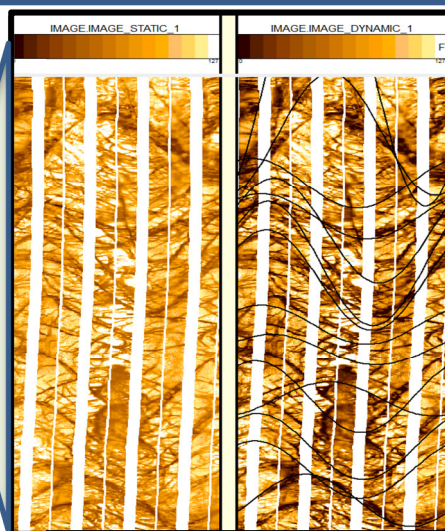


Stonely Frac. analysis

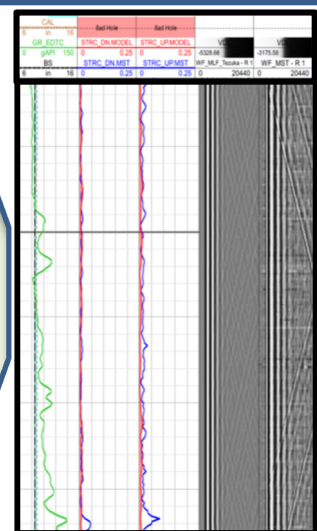
Fig 3: Well – A: Log Motifs



Conventional Log

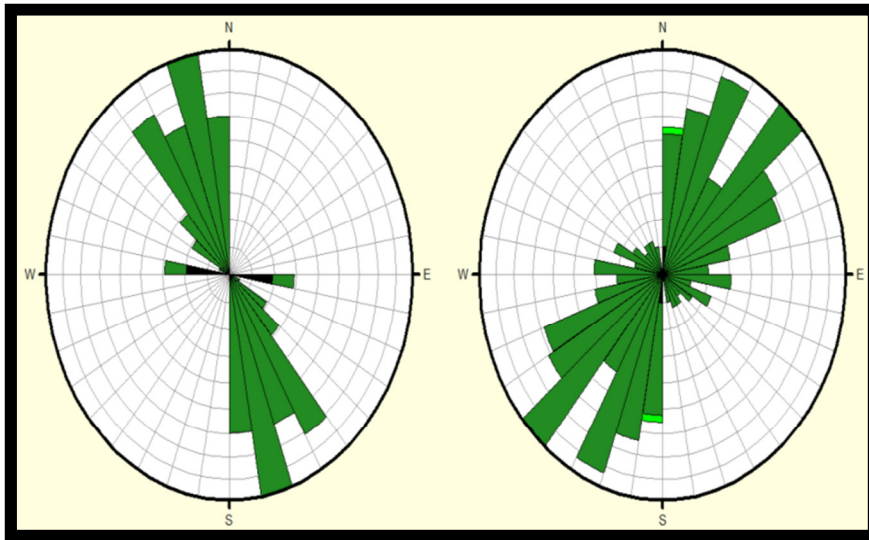


Resistivity Image Log

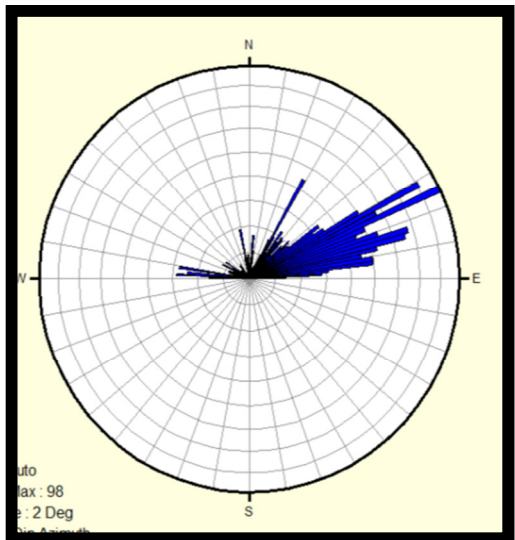


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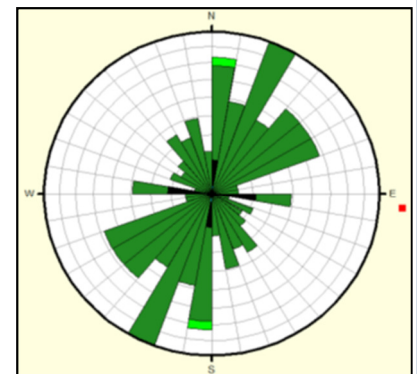
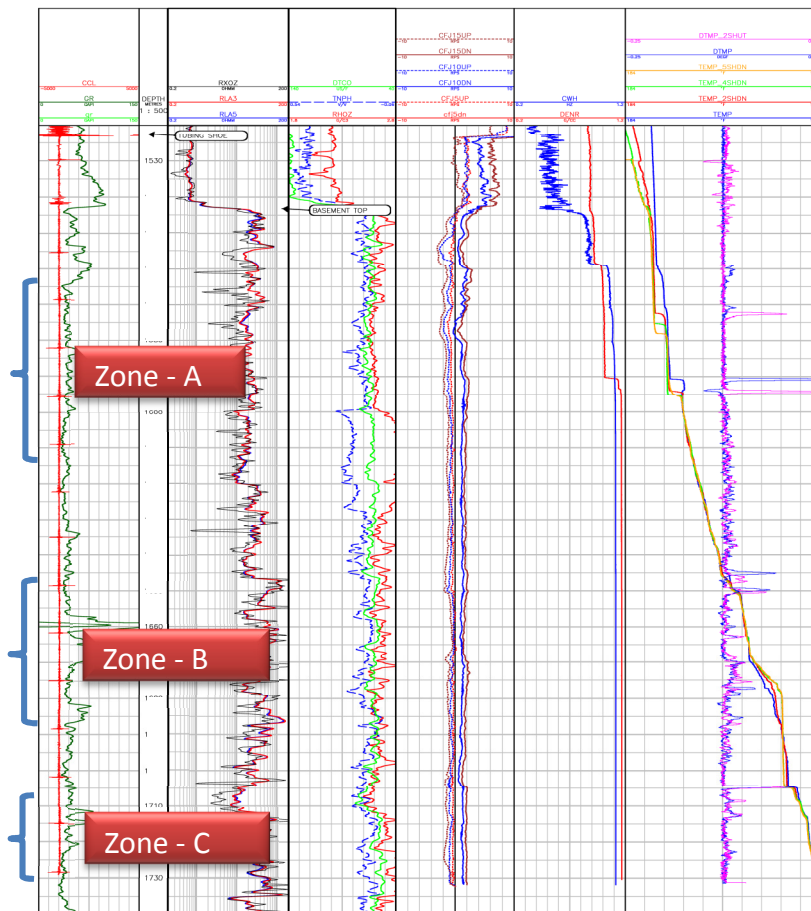
Fig-3: Well – B: Log Motifs



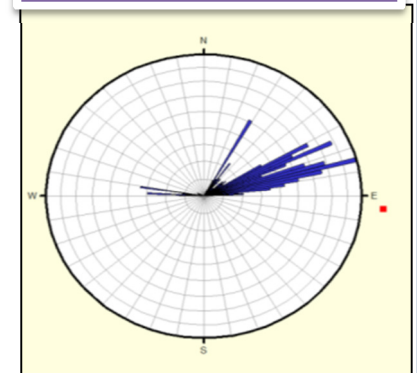
Fracture Strike direction - FMI



Fast shear Azimuth



Fracture Strike direction
(Zone-A, B&C)



Fast shear Azimuth
(Zone-A, B&C)

Fig - 4: Well-A: Mainly two set of fractures are seen (NE-SW and NW-SE) with dominant fractures are along SHmax. From PLT log, Major producing intervals (ZONE-A, B&C) are identified and fracture strike direction of producing intervals is predominantly NE-SW dir.

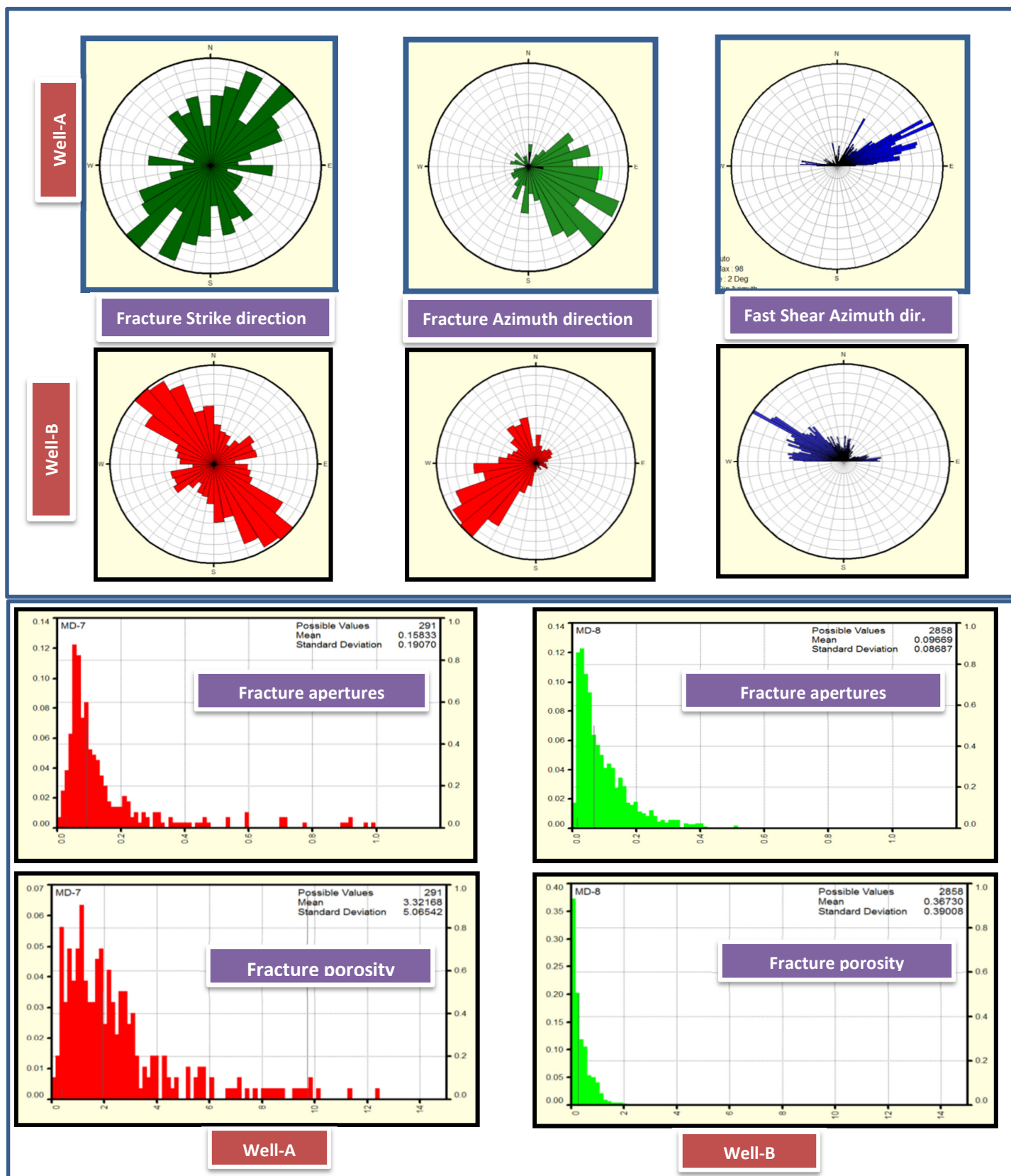


Fig-5: Comparison of Well-A and B: In Well-B, dominant fracture strike direction is not in line with regional principle stress direction. Fracture attributes histogram shows Well-A having better fracture attributes than well-B.