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How to characterize fractures in oil and gas reservoirsusing image logs and the other geological logs, a case study

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ABSTRACT

Fracture characterization means finding out the fracture type, fracture strike, fractures dip, fracture aperture, fractureoccurrence, fracture density and any other information related to fractures. In oil and gas industry, havingthis informationabout the fractures are essential, because of the importance that they have in oil and gas reservoirs. Fractures provide the place for oil and gas to stay and to provide the pathway for them to moveinto the well. In other word, doing any operation in oil and gas reservoirsdepends onfracture characterization, especially in naturallyfractured reservoirs. Image log technology is the new technology that can provide us this information, but this technology is still unknownto many geologists, so we will explain it completely using a case study and a number of valuable selected log interpretation examples.

KEYWORDS

Fracture characterization;
Oil and gas reservoirs;
Image log technology.

INTRODUCTION

Gachsaran oil field is in the southwest of Iran (Figure 1) with an anticline structure, made of anhydrite/ salt, 80 km long, 300m-1500m thickness, 8-18 km wide; it provides an excellent seal for Asmari reservoir, Pabdeh reservoir, Gurpi reservoir and the other reservoirs located under it (Figure 2)[1].

In this work, 3 wells located in Gachsaran oil field will be selected, and the fracture characterization will be done in these wells by using the image logs and the other geological logs interpretation. We will do the fracture characterization in order to both having a better understanding of structural geology in this field and also explaining the methodology by showing the selected log interpretation examples from this field.

By using the image log technology, we can do the fracture characterization very well; by interpreting the image logs, we will find out thefractures strike/dip, fractures classification, fracturesoccurrence, fractures aperture and fractures density[2]. In this work we will select 3 wells, located inGachsaran field that are logged with 3 different image loge tools, FMS, OBMI and FMI, then we will explain the process completely.

MATERIALS AND METHODS

For this job, we selected 3 wells, located in Gachsaran field, which are logged with 3 different types of image log tools, so that we can cover almost all the

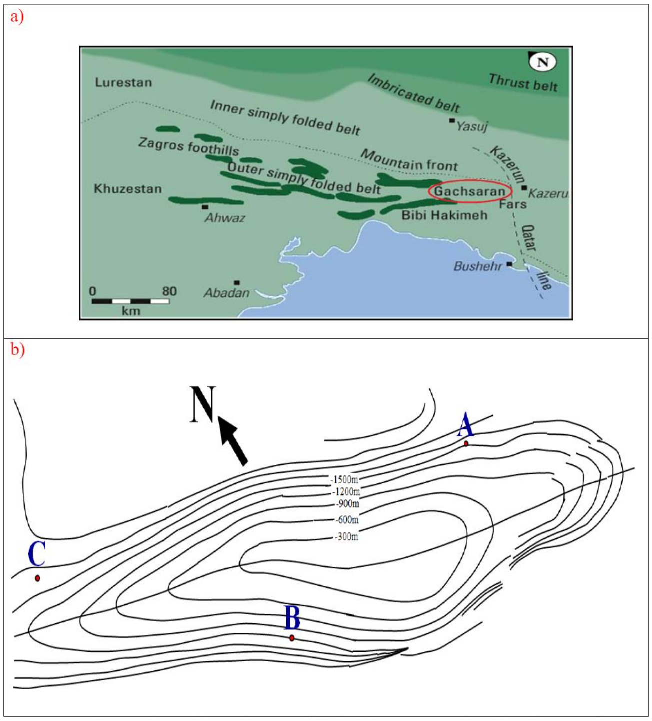

Figure 1 : a) Location of theGachsaran oil field; b) UGC map the of Gachsaran oil field and the studied wells

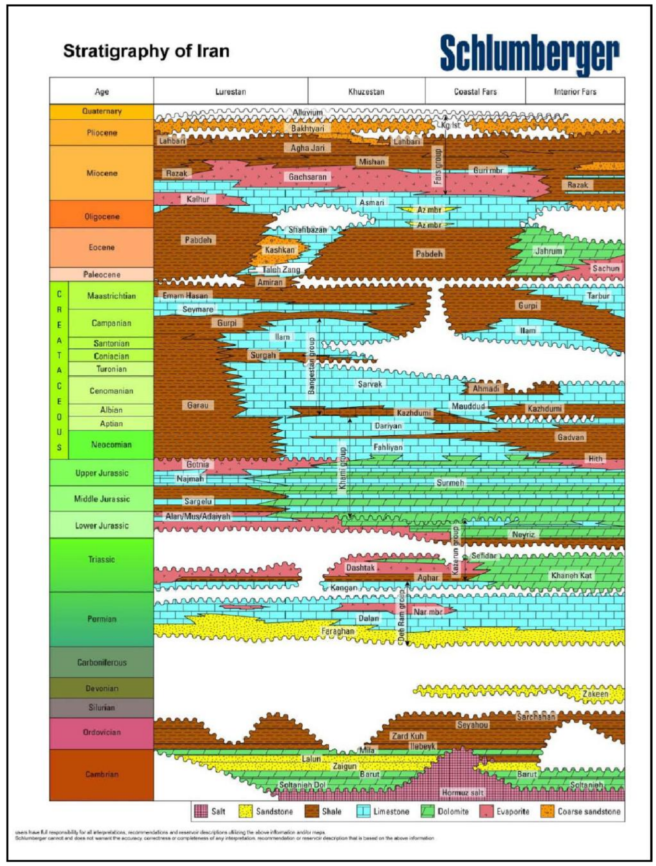

Figure 2 : The location of Gachsaran oil field overlying the Asmari, Pabdeh, Gurpi and the other reservoirs, and stratigraphic nomenclature of rock units and age relationships in the Zagros basin

aspects of the fracture characterization job using image log technology. The main data for this job are the image log data including the Formation Micro Scanner (FMS) for well number GS-A, Formation Micro Imager (FMI) for the well number GS-B, and Oil-Base-Mud Imaging (OBMI) and Ultrasonic Borehole Imager (UBI) for the well number GS-C.

In geology, fractures are the features that have been created in rocks and they have the different dip from the rocks / layers structural dip so they can be recognized. The way that they will be created is due to movements in original rocks and these movements are due to one or more forces in place. These forces can be originated from the faults, folds, diapirisms, plate movements and so on. Recognizing the fractures has always been an important matter for geologists and many methods have been created to do this task, but the image loge technology is different from the other techniques with many benefits that in this job we will prove these advantages. On the FMS, FMI, OBMI and UBI images, fractures appear as linear features that generally have a dip more inclined than the structural dip[3&4].

On the FMS and FMI images, open fractures in a clay free formation have a conductive appearance on the images due to invasion of their aperture with the conductive drilling mud. While the mineralized or sealed fractures appear resistive if the filling material of their apertures is dense like calcite or anhydrite. However, the fractures having a clay or pyrite filling have a conductive response. To differentiate between the mud filled and clay/pyrite filled conductive fractures, knowledge of the depositional and stratigraphic setting of the study area is imperative. In some cases, open hole logs can also be very helpful for such kind of differentiation.

On the OBMI and UBI images, open fractures and the fractures with their apertures filled with resistive material, like calcite and anhydrite, have the same resistive appearance. Closed fractures can be differentiated from the open fractures using the amplitude image of UBI that decrease in front of the open fractures filled with oil-base mud, thus open fractures appear as darker linear features on the UBI amplitude image. Whereas the calcite / anhydrite filled fractures do not affect the amplitude image because the rock matrix and the fracture filling material have more or less the same amplitude range. However, in some cases such filled fractures can be seen on the amplitude images when there is some amplitude contrast between the rock matrix and the fracture filling material[5] (Figures 3 & 4).

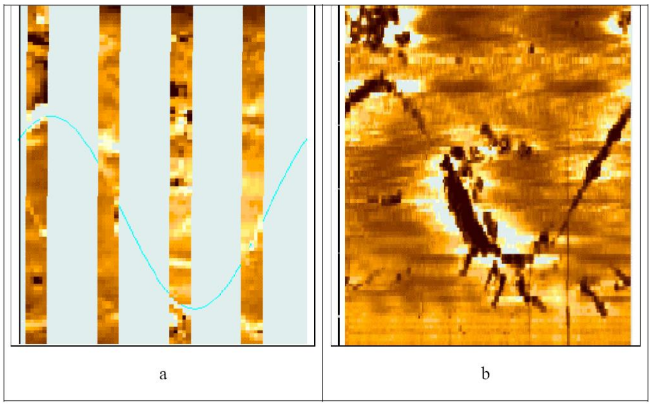

Figure 3 : a) OBMI - open fracture appears resistive due to invasion of oil-base-mud along its plane; b) UBI - same fracture has low amplitude on UBI amplitude image, indicating its open nature

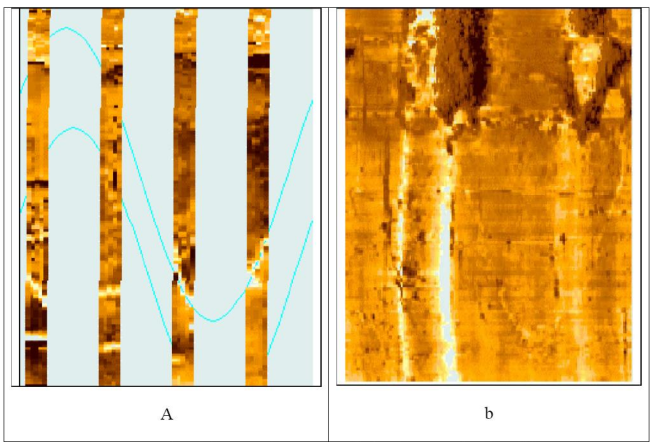

Figure 4 : a) OBMI – closed fracture shown as resistive due to anhydrite filling of its aperture; b) UBI – the same closed fracture has a lighter shade trace on the UBI amplitude image due to higher amplitude caused by denser filling material

The clay / shale filled fractures have conductive appearance on the OBMI images due to no invasion of oil-base mud along the planes. On the UBI amplitude image, such clay filled fractures will have lower amplitude but not as low as mud-filled fractures.

RESULTS AND DISCUSSION

Fracture characterization in the well number gs-a

Fracture analysis was the main objective of FMS survey in the study well. To get the maximum knowledge on fractures, the images were interpreted in conjunction with openhole logs. Discussion on various fracture attributes is given in the following:

(a) Fracture classification

The FMS images revealed a number of fractures in most zones of the Asmari formation. Altogether 759 open fractures were identified. Closed fractures appeared to be absent in the Asmari formation at the present location of the well.

The open fractures have a variation in their appearance and trace continuity across the wellbore (Figures 5 & 6). Therefore based on their lateral continuity within the wellbore, the open fractures are classified into two categories; partially closed open fractures and continuous open fractures. There are 742 partially-closed open fractures, which apparently do not have complete continuity of their traces across the wellbore (Figure 6). The open fractures (continuous), which are 17 in number, appear to have better continuity of their traces

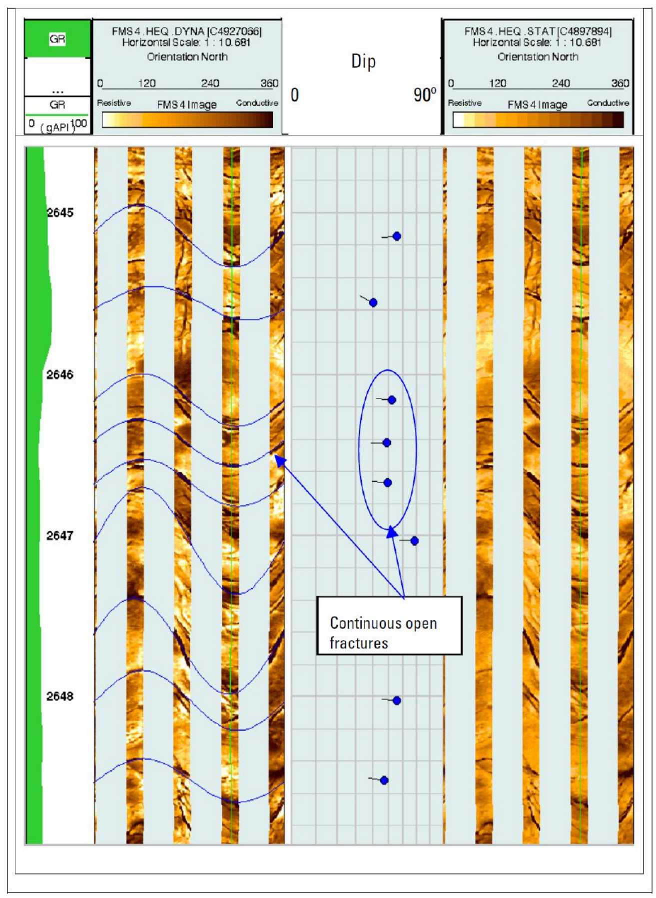

Figure 5 : Continuous open fractures in Asmari formation

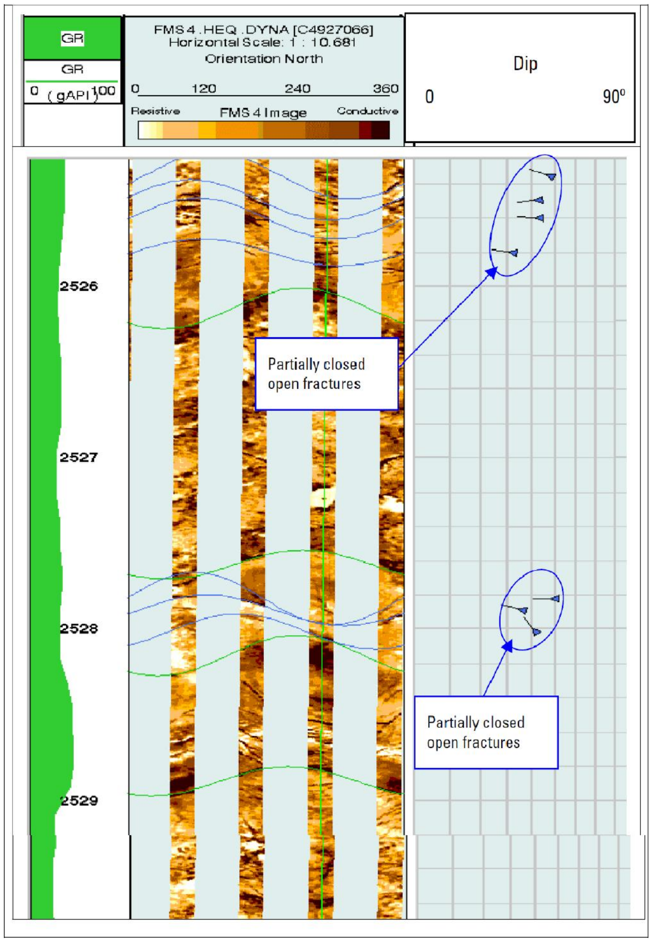

Figure 6 : Partially closed open fracture and bedding in Asmari formation

across the wellbore (Figure 6).

(B) fracture dip / strike

The dip and strike properties of partially-closed open fractures and continuous open fractures are almost the same. Their dominant dip inclination is 65 degrees but it varies from 45 to 75 degrees. They dip dominantly to West with 30 degrees spread on both sides and have a dominant strike of N-S.

Based on the dominant N-S strike of both sets of open fractures and N63W-S63E bedding strike, it seems that most open fractures are oblique to the structural / fold axis of the Gachsaran field in the area around the study well (Figure 7).

(c) Fracture density

Density of open fractures was computed to represent number of fractures per meter. Density of open fractures is higher in some zones. Based on fracture density curve, there are a number of high fracture density zones: 2695-2692m, 2668-2666m, 2650-2638m, 2604-2601m, 2572-2569m, 2499-2496m, 2494-2492m, 2490.5-2488m, 2486-2482m, 2422.5-2420m, 2398.5-2396, 2394-2391m and 2385-2380m (Figures 8&9).

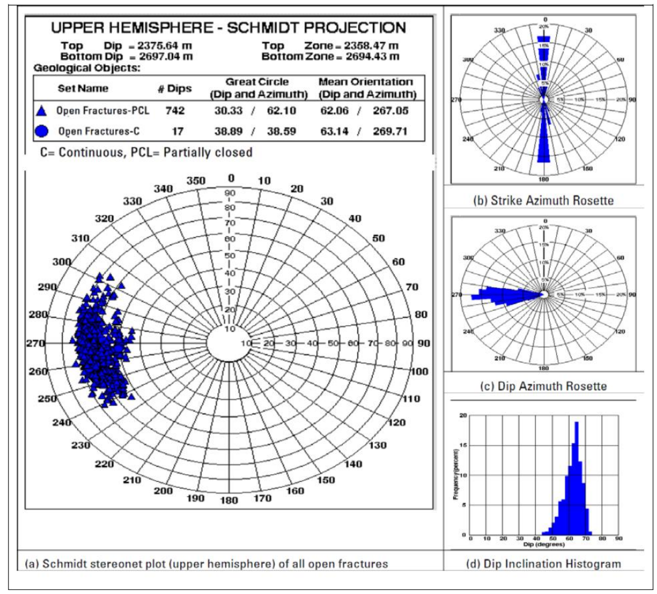

Figure 7 : Statistical plots for the dips of all open fractures identified in the Asmari formation

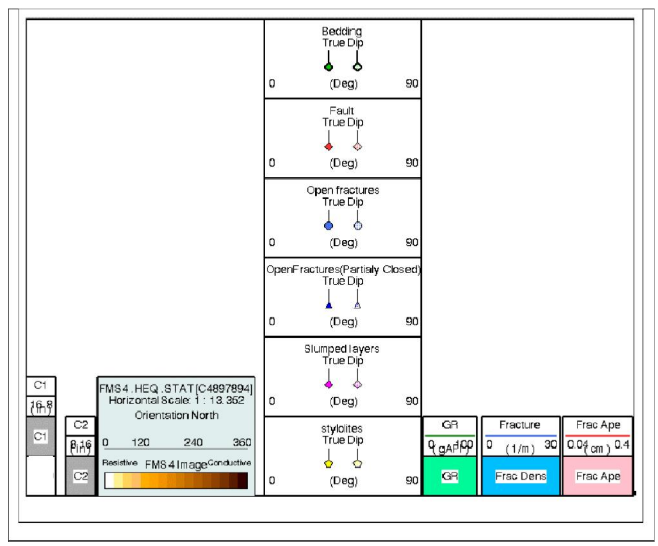

Figure 8 : Header details for Figure 9

Fracture characterization in the well number gs-b

Fracture analysis is one of the most important objectives of FMI survey. The images were interpreted in conjunction with openhole logs so that a certain correlation could be established between fracture occurrences observed in the FMI images and logs response, sonic, nuclear (LDT-CNL) and resistivity logs run in

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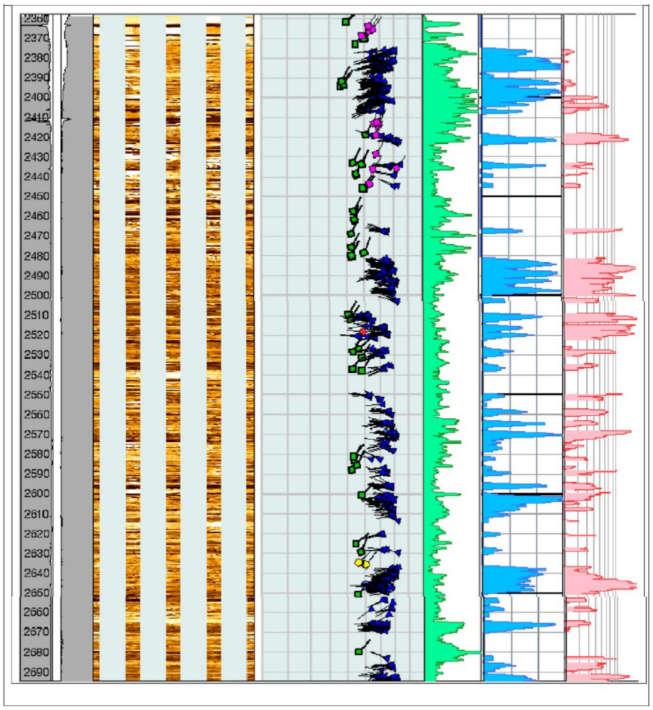

Figure 9 : Summary plots of fracture analysis results; see Figure 8 for header details

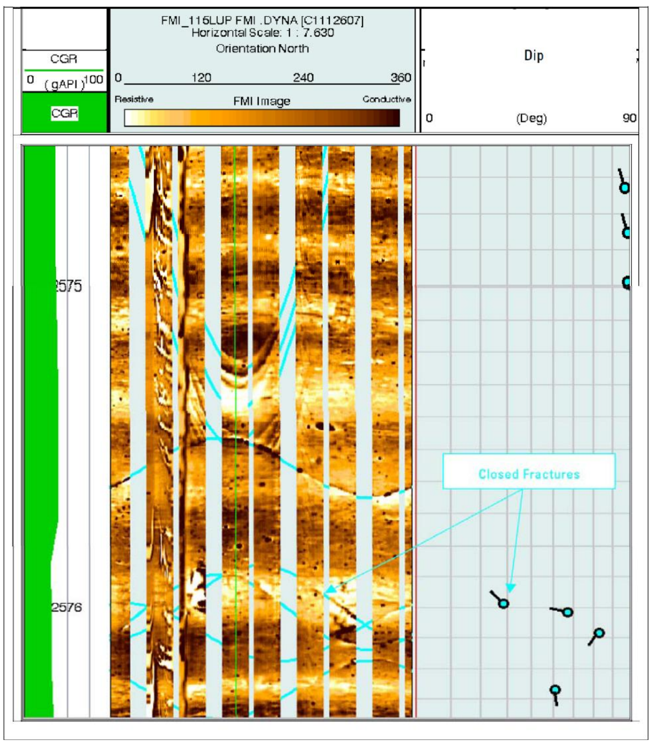

Figure 10 : Example of closed fractures in Gurpi formation seen by the FMI

the study well. Discussion on various fracture attributes is given in the following:

(a) fracture classification

The FMI images revealed a small number of fractures in certain zones of the Gurpi, Pabdeh and Asmari formations. Altogether 112 fractures were interpreted. Not all fractures have the same appearance as some of them have resistive appearance and some have con-

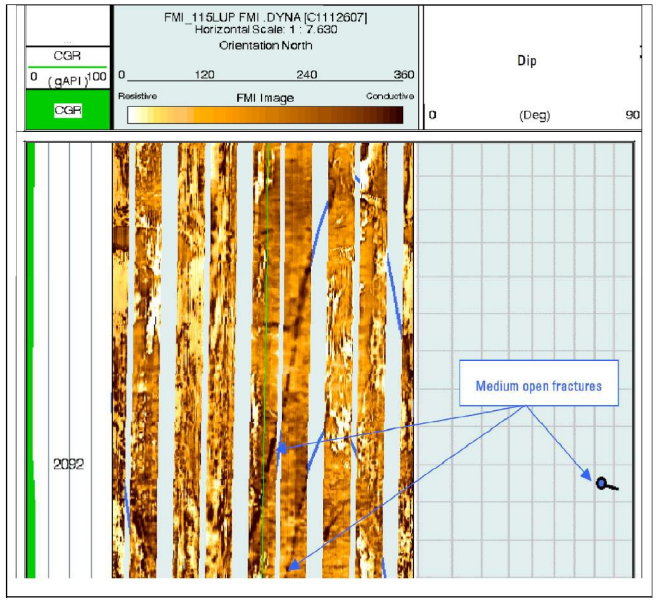

Figure 11 : Example of medium open fractures in Asmari formation seen by the FMI

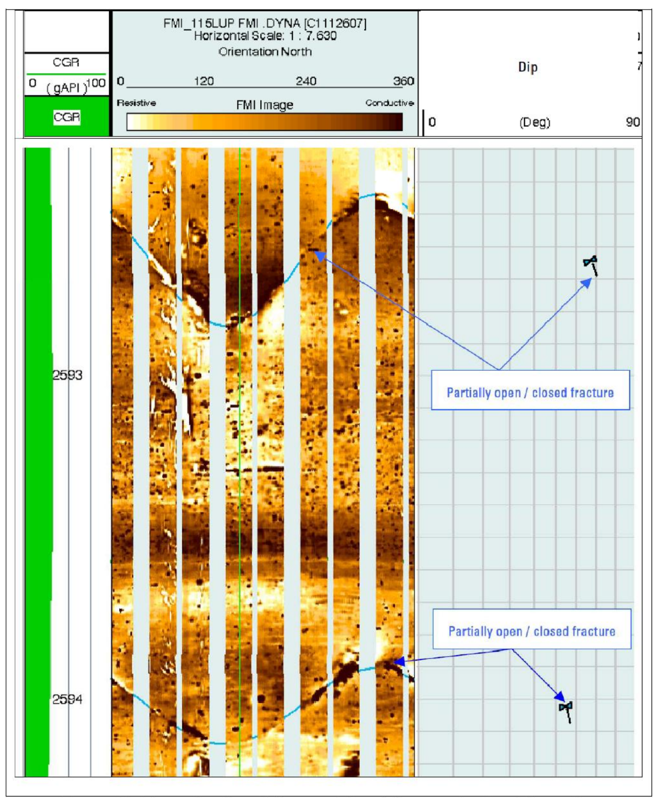

Figure 12 : Example of partially open/closed fractures in Gurpi formation

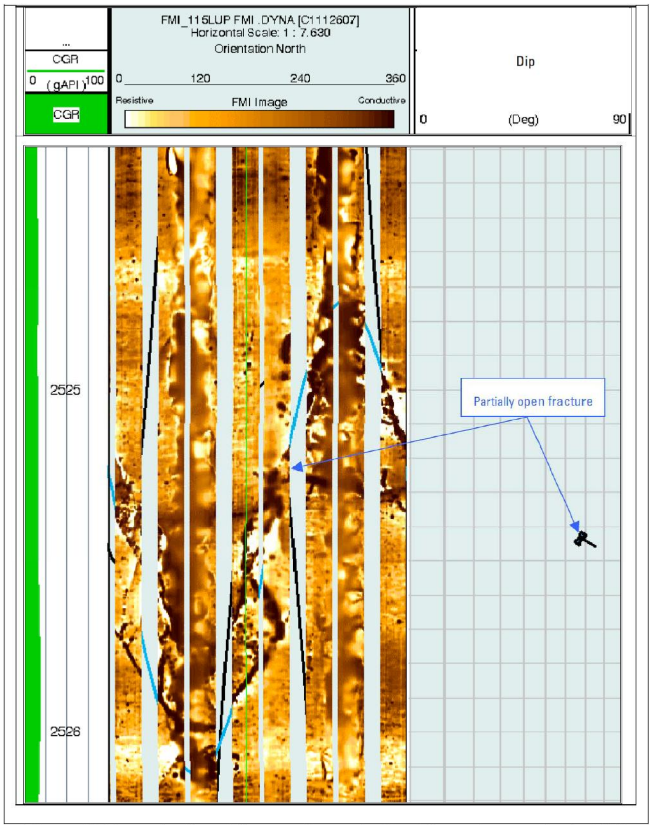

Figure 13 : Example of partially open fracture in Gurpi Formation seen by the FMI

ductive appearance. There are 92 fractures the traces of which appear either resistive or tight on the images (Figure 10). All such fractures are classified as closed fractures.

All the fractures that have continuous or discontinuous conductive traces are termed as open fractures. Their conductive nature is due to mud invasion into the open sections of their planes. Open fractures are further classified into more classes based on their appearance and continuity within the wellbore (Figures 11, 12& 13).

The characteristics of open and closed fractures and their sub-categories are given in the following table.

(B) fracture dip / strike

The closed fractures form two clear sets as far as orientation (Figure 14). The open fractures have two dominant dip azimuths (Figure 15).

Dip attributes of both closed and open fractures are given in the following table

(C) fracture occurrence

Open fractures are observed in two zones, which

TABLE 1 : Fracture classification

Main Fracture Type	Fracture Classes	Image Appearance	Seen by Images	Number of Fractures	Symbol	Explanation
Closed Fractures	Filled / Tight Continuous	Resistive	7-8 images	-	△	Fractures traces are continuous and not stopping on the bed / layer boundaries. Their aperture is either very tight or filled with some dense material.
	Filled / Tight Discontinuous	Resistive	Less than 6 images	92	○	Fractures traces are discontinuous and may or may not stopping on the bed / layer boundaries. Their aperture is either very tight or filled with some dense material.
	All Closed Fractures	Resistive	-	92	-	-
Open Fractures	Major	Conductive	7-8	-	■	Fracture trace with relatively thick apparent aperture and present across the wellbore
	Medium	Conductive	7-8	4	●	Fracture trace with relatively medium apparent aperture and present across the wellbore
	Minor	Conductive	7-8	-	▲	Fracture trace with relatively thin apparent aperture and present across the wellbore
	Vuggy	Patchy Conductive	< 5	-	+	Fractures with patches of varying size open aperture at places
	Partially Closed	Patchy Conductive	=< 4	16	⋈	Similar to the vuggy fractures , but the tight/closed sections of the fractures trace are generally clear
	Possible open	Conductive	=<4	-	◀	Present in two alternate pads, look similar to the drilling induced fractures
	All Open Fractures	Conductive	4-8	20		

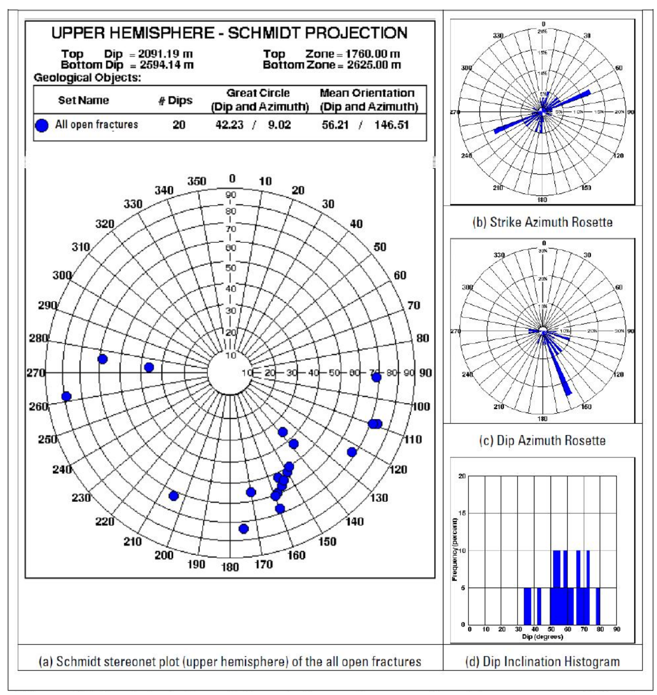

Figure 14 : Statistical plots of dips of all open fractures, found in upper part of Gurpi formation, Pabdeh and Asmari formations

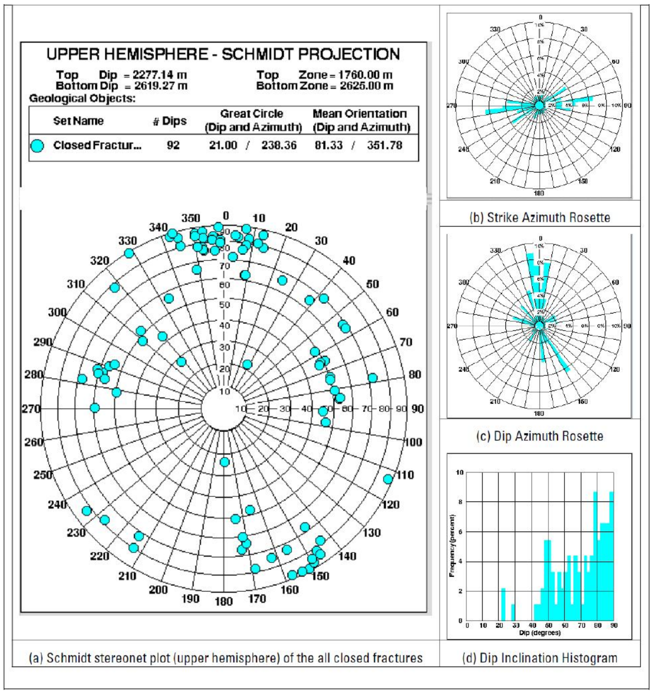

Figure 15 : Statistical plots of dips of all closed fractures, found in Gurpi, Pabdeh and Asmari formations

TABLE 2 : Fractures dip attributes

Main Fracture Type	Fracture Classes	Dominant Dip Azimuth (deg)	Azimuth Spread (deg)	Dominant Strike (deg)	Strike Azimuth Spread (deg)	Dominant Dip Inclination (deg.)	Inc. Range (deg)
Closed Fractures	Filled / Tight Discontinuous	N2W S32E	15	N82E-S82W N58E-S58W	25	79&89	22-90
Open Fractures	Medium	S72E	30	N10E	10	37&71	36-74
	Partially Closed	S23E	10	N67E-S67W	10	34,59,67	34-80
	All Open Fractures	S23E	S85E-N85W	N67E-S67W	20	56,71	34-80

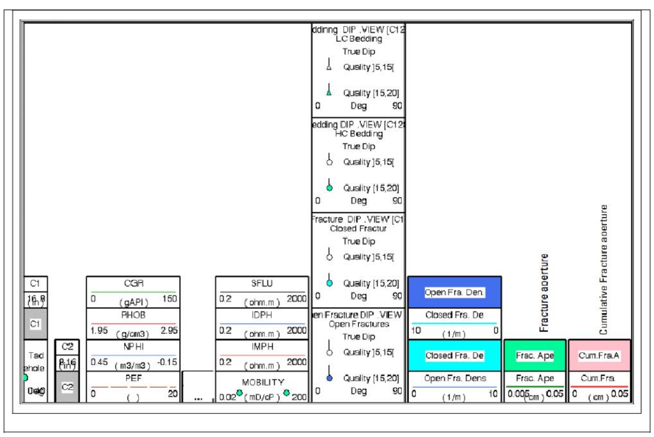

Figure 16 : Header for the summary plot of Figure 17

are 2091-2094m and 2507-2525m. Closed fractures exist in upper part of Gurpi formation, and lower parts of Pabdeh and Asmari formations (Figures 16 & 17& TABLE 3).

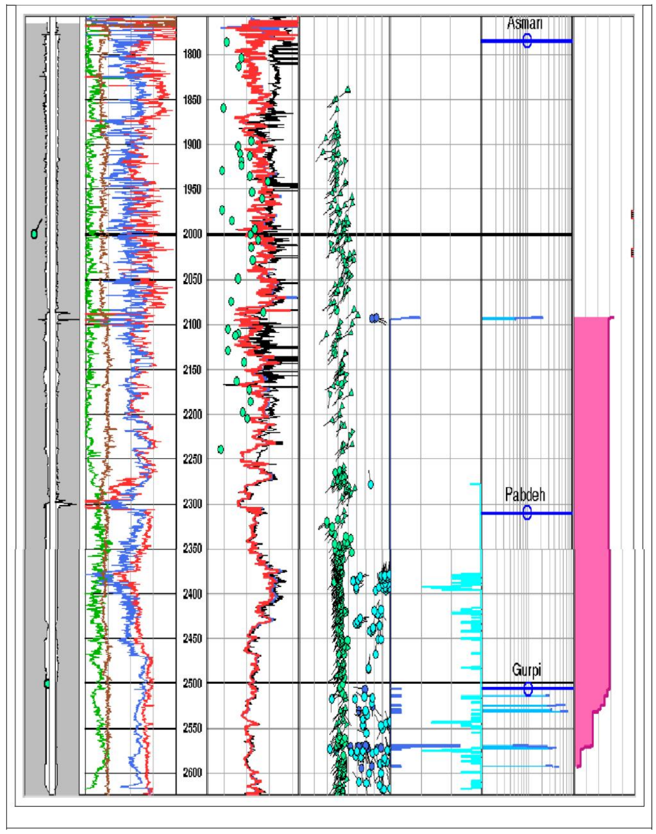

Figure 17 : Summary log of resistivity, density, porosity, dips, fractures density and apertures in Gurpi, Pabdeh and Asmari formations

TABLE 3 : Fractures occurrence

Main Fracture Type	Fracture Classes	Main Fractured Intervals (m)	Formation	Dominant Lithology
Closed Fractures	Filled / Tight Discontinuous	2378-2396, 2417-2444, 2450-2452, 2515-2546	Asmari, Pabdeh, Gurpi	Limestone
Open Fractures	Medium Open Fracture	2092-2094, 2515-2516	Gurpi, Asmari	Limestone
	Partially Open	2507-2532, 2570-2576, 2594-2595	Gurpi	Limestone
	All Open Fractures	2092-2595	Asmari, Pabdeh, Gurpi	Limestone

(D) Fracture density

Density of open and closed fractures was computed to represent number of fractures per meter. The zone of highest density of open fractures is 2570-2574m. The average value for open fractures density is 1.5 per meter. Density of closed fractures in Gurpi formation and lower and middle part of Pabdeh formation is the highest (Figure 17& TABLE 4).

Fracture characterization in the well number gs-c

Fracture analysis is one of the most important ob-

TABLE 4 : Fractures density

Main Fracture Type	High Fracture Density Intervals (m)	Formation / Zone	Dominant Lithology
All Closed Fractures	2378-2396, 2543-2548, 2574-2578	Pabdeh, Gurpi	Limestone
All Open Fractures	2570-2572	Gurpi	Limestone

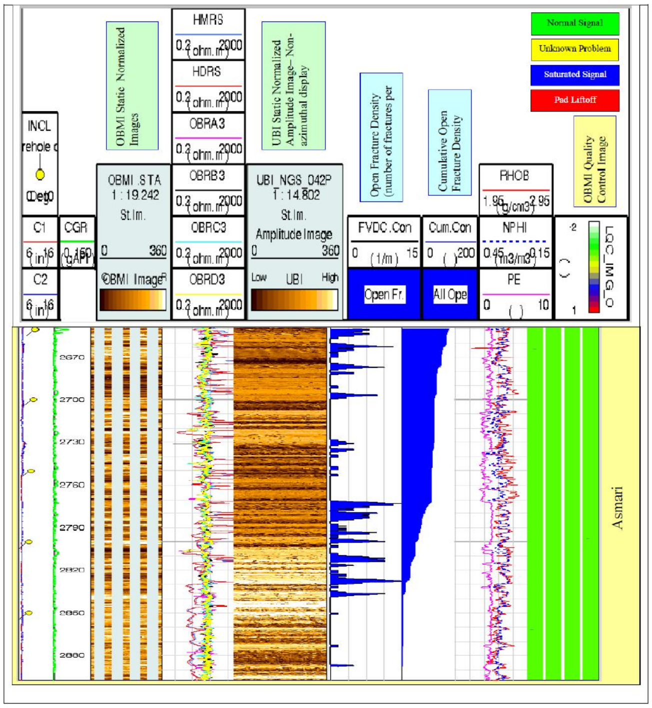

Figure 18 : Composite plot of orthogonal calipers (C1 and C2), deviation, CGR, OBMI static normalized images, OBMI Rxo curves, UBI static normalized amplitude image, open fracture density curve, cumulative fracture density curve, RHOB and NPHI and PEF curves, and OBMI LQC image

jectives of oil-base-mud imaging in the study well. Both electrical (OBMI) and acoustic (UBI) amplitude images were analyzed to identify fractures (Figure 18). Discussion on various fracture attributes is given in the following:

(a) fracture classification

OBMI and UBI amplitude images were used to identify open and closed fractures because UBI mainly sees open fractures while the same open fractures appear resistive on the OBMI images. Fracturing is observed in certain intervals in this well, particularly in 2650-2658m, 2660-2670m, 2675-2682m, 2694-2700m, 2728-2740m, 2770-2800m, and 2808-2840m.

Large majority of fractures have low amplitude traces on the UBI amplitude images and resistive appearance on the OBMI images; hence classified as open fractures. These fractures are further classified into continuous-open and discontinuous-open based on the lateral continuity of their low-amplitude traces on the acoustic amplitude images of UBI (Figures 19 to 24).

The characteristics of open fractures and their subcategories are given in TABLE 5.

(b) Fractures' dip & strike

Both continuous and discontinuous open fractures make main clusters in the western region of the Schmidt stereonet, particularly around N265E and N295E, but with quite broad azimuthal ranges. In addition to that some smaller clusters can be seen in the northwest, southwest and southeast region. Most of fractures are plotted within 65 and 80 degrees inclination circles of the stereonet. On the dip azimuth rosette, discontinuous open fractures show a dominant dip azimuth around

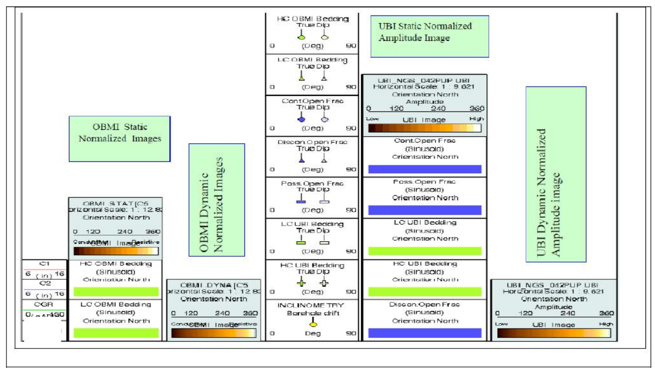

Figure 19 : Header detail for Figures 20 to 24

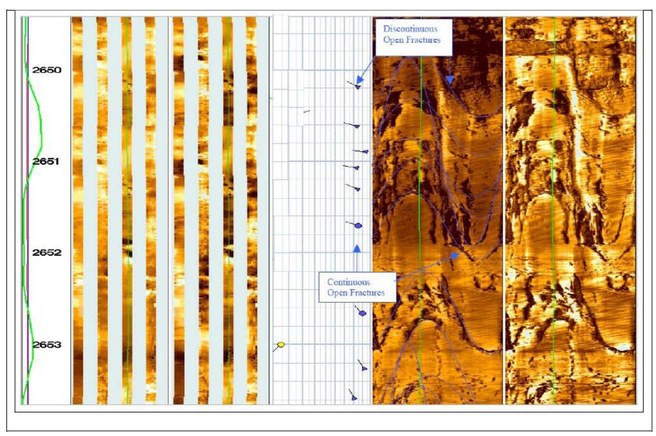

Figure 20 : Continuous (blue circular dips) and discontinuous (blue triangle dips) open fractures shown by UBI images in the lower part of Asmari formation. Header details are given in Figure 19

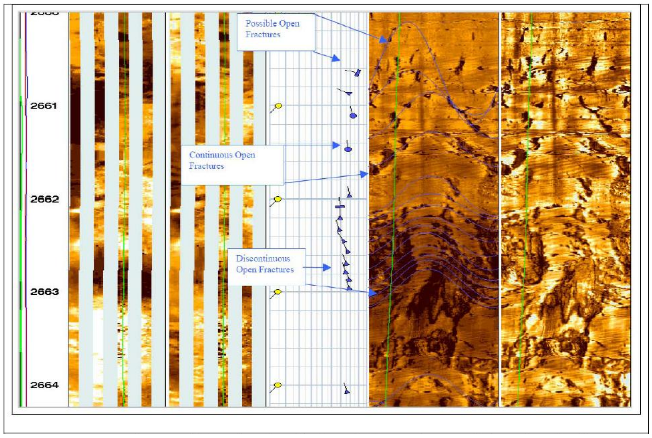

Figure 21 : Continuous (blue circular dips) and discontinuous (blue triangle dips) and possible (blue minus sign symbol dips) open fractures shown by UBI images in the lower part of Asmari formation. Header details are given in Figure 19

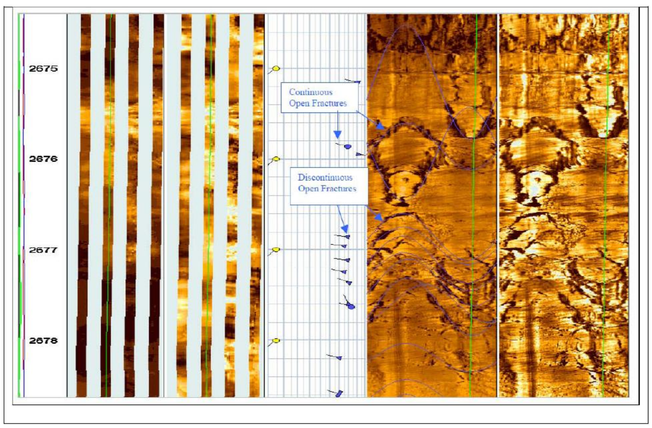

Figure 22 : Continuous (blue circular dips) and discontinuous (blue triangle dips) and possible (blue minus-sign symbol dips) open fractures shown by UBI images in the lower part of Asmari. Header details are given in Figure 19

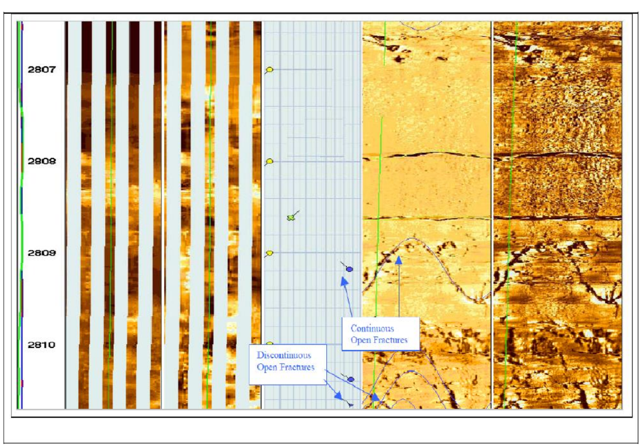

Figure 23 : Continuous (blue circular dips) and discontinuous (blue triangle dips) open fractures shown by UBI images in the lower part of Asmari. Header details are given in Figure 19

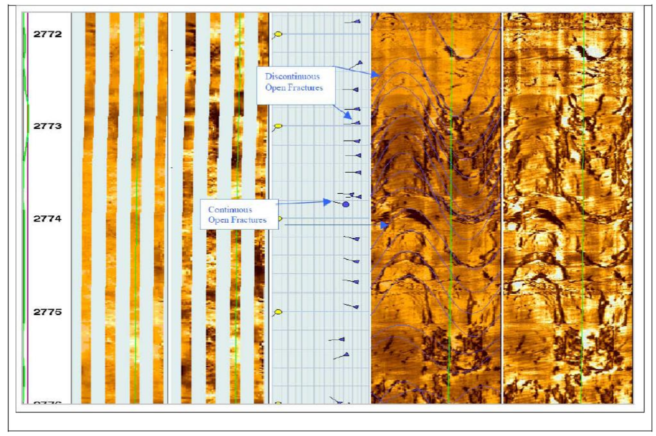

Figure 24 : Continuous (blue circular dips) and discontinuous (blue triangle dips) open fractures shown by UBI images in the lower part of Asmari. Header details are given in Figure 19

TABLE 5 : Fracture classification

Main Fracture Type	Fracture Classes	OBMI Image Appearance	UBI Amplitude low / high	Number of Fractures	Symbol	Explanation
Open Fractures	Continuous Open	Resistive	Low	12		Visible on 4 pads of OBMI and most part of the UBI amplitude image
	Discontinuous Open	Resistive	Low	164		Visible on 1-3 pads of OBMI and has patchy appearance on UBI amplitude image
	Possible Open	Resistive	Low	70		Visible on 1-3 pads of OBMI with patchy appearance on UBI amplitude image
	All Open	Resistive	Low	176		All open fractures include continuous and discontinuous fractures only

N58W (Figure 25).

There are two other sets as well which dip dominantly to the N72W and N62W. On the strike azimuth rosette, therefore, they make three clear strike directions, N32E-S32W, N18E-S18W and N28E-S28W with overall spread of 25 degrees. Their dip inclination also makes a wide spread but most of them have dip inclination between 65 and 80 degrees with 75 degrees being the dominant value (Figure 25).

Continuous open fractures show a dominant dip azimuth of N70W with 30 degrees spread on the dip azimuth rosette and a strike of N20E-S20W with the same amount of spread. Their dip inclination also makes a wide spread but most of them have dip inclination between 72and 76 degrees with 73 degrees being the dominant value (Figure 25).

Although not very accurate, possible open fractures dip dominantly to S83W at 48 to 80 degrees inclination and strike N3W-S3E with a large scatter (Figure 25 & TABLE 6).

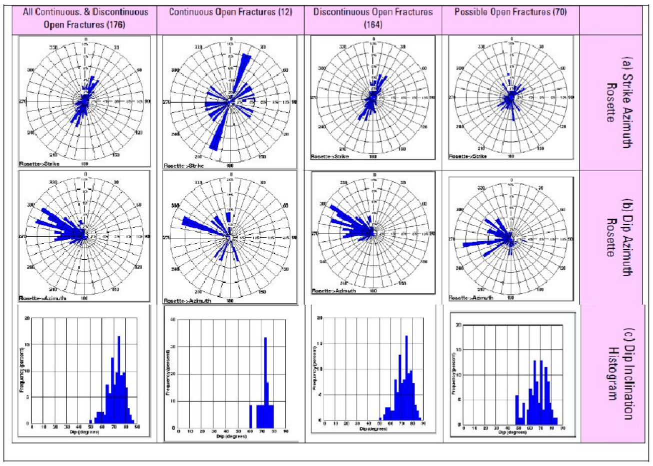

Figure 25 : Statistical plots of dip attributes of all open fractures, continuous open fractures and discontinuous open fractures and possible open fractures

TABLE 6 : Dip attributes of fractures

Main Fracture Type	Fracture Classes	Average/ dominant Dip Azimuth	Azimuth Spread	Average / dominant Strike	Strike Azimuth Spread	Dominant Dip Inclination (deg.)	Inclination Range (deg.)
Open Fractures	Continuous Open	N70W	30	N20E-S20W	30	73	60-80
	Discontinuous Open	N58W, N62W, N72W	25	N32E-S32W, N28E-S28W, N18E-S18W	25	75	50-88
	Possible open	S83W	25	N7W-S7E	40	65,71	48-86
	All Open	N58W, N72W	25	N32E-S32W, N18E-S18W	25	75	50-88

Based on both continuous and discontinuous open fractures, two dominant dip azimuths, N58W and N72W, can be marked. The average dip azimuth of these two dominant sets of open fractures is N65W with the average strike of N25E-S25W. So these values can be taken to indicate the main trend of open fractures in the study well.

(c) Fracture density / occurrence

Fractures are found at a number of places throughout the Asmari formation. In relation to lithology, most fractured zones exist in dense to low porosity limestone. The dolomitic and higher porosity limestone zones tend to have least development of fractures. There are two main zones at 2650-2700m and 2770-2840m, where most fractures exist. A number of short fractured sections exist within these two zones, which include 2650-2658m, 2660-2670m, 2675-2682m, 2694-2700m, 2728-2740m, 2770-2801m, and 2808-2840m. In some of these sections, fracture density reaches as high as 13 fractures per meter. On the average, the two fractured zones have 5-7 open fractures per meter (Figure 26).

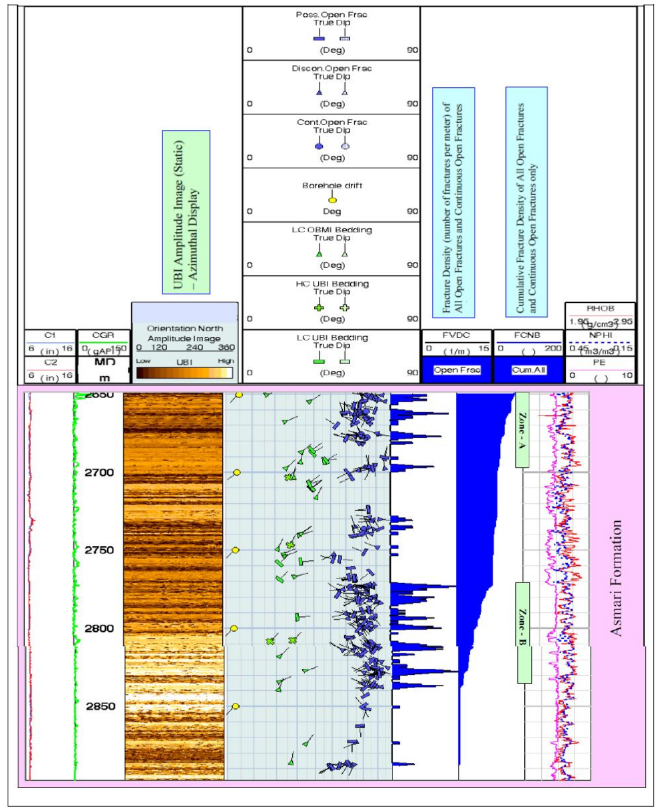

Figure 26 : Summary of fracture analysis results in GS-C; Open fractures are present in most interval (Two zones 2650-2700m and 2770-2840m)

Fracture characterization for all the studied wells

After doing the fracture characterizationof all the studied wells, as an example, we will show the natural fractures strike map of Asmari reservoir in Gachsaran field for all the studied wells in one picture in order to show the results in a better way and discus them easier (Figure 27).

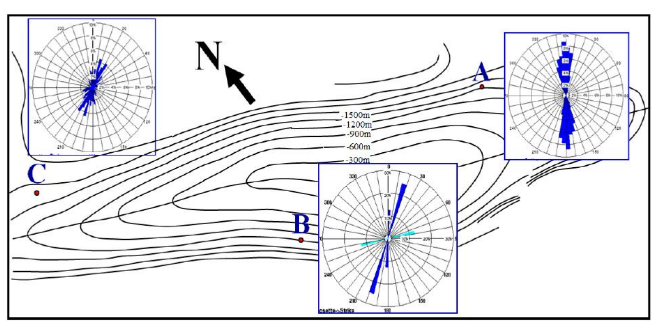

Figure 27 : Natural fractures (conductive, resistive) strike map in Asmari formation ofGachsaran field

CONCLUSION

This job showed that how effective is image log technology to do the fracture characterization. This job was a case study that we did in Gachsaran field; we selected 3 wells that were logged by 3 different image log tools (FMS, UBI/OBMI and FMI), and we studied them. We hope that we could prepare a good educational paper in order to show the way that we can do the fracture characterization using image log technology by showing a number of proper loge interpretations in this case study.

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