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Systematic fractures analysis using image logs and complementary methods in the Marun Oilfield, SW Iran

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Abstract
Fractures are considered as one of the important structures in fractured reservoirs due to their effect on fluid currents and reservoir parameters such as porosity and permeability. Fracture parameters can only be directly calculated with core and image logs. Cores have serious limitations, so image logs are the best method. The aim of this study is the systematic fractures analysis of the Asmari Formation in the Marun field as one of the giant oilfields in world. The main objectives of image logs were evaluating structural dip, characterizing natural fractures and field structure heterogeneity, and finally correlating the results with complimentary methods such as Velocity Deviation Log (VDL), Repeat Formation Test (RFT), mud lost data, and isodip map in the carbonate Asmari Formation. Generally, electric and ultrasonic imaging tools record vast amounts of high-resolution data. This enables geoscientists to describe in detail the structural fracture networks. The results indicate that the highest fracture density is in the zones 1, 20, and 30 of the Asmari reservoir that show high correlation with VDL and mud lost data. Image logs also show a range of bedding dips from 20˚ in the northern limb to 30˚ in the southern limb with strikes ranging from 10˚ to 270˚N. Regarding the general pattern of fractures, it is evident that they are related to the folding and are classified mainly as longitudinal, transverse, and oblique. The longitudinal pattern is dominant and often forms open fractures. They are characterized by N50W-S50E and mainly observed in the upper Asmari zones. Moreover, to find the vertical relation of the layer and fractures, RFT data were used. The findings revealed the presence of a vertical relation in the upper horizons of the reservoir, especially in the eastern section due to the high fracture density.

Keywords: *Asmari Reservoir, Complimentary Methods, Fracture Analysis, Image Logs, Marun Oilfield.*

Introduction

Some direct and indirect methods were used for the determination of reservoir parameters including seismic section, petrophysical logs, well test, cores, and image logs (Thompson, 2000; Tingay *et al*., 2008). Image logs and cores are the best methods for the analysis of reservoir parameters. However, cores have serious limitations such as high cost, low recovery in fractured interval, and changing core orientation during coring (Mohebbi *et al.*, 2007; Khoshbakht *et al.*, 2009). In the recent years, image logs have become the most important and advanced fracture analysis methods for reservoir evaluation (Khoshbakht *et al.*, 2012). These methods have been improved rapidly due to their excellent ability in characterizing the borehole features such as fractures and bedding (Serra, 1989). Image log studies reduce expenditure owing to the reducing coring depths and perforate zone determination. The presence of fractures has a considerable impact on permeability (Rezaee & Chehrazi, 2005) and knowledge about them and their patterns help in the determination of the best location for drilling and maximum exploration (Serra and Serra, 2004). It is now generally understood that fractures have a vital role in the production and migration of oil in the Zagros basin (Alavi, 2004, 2007). They are important features in the carbonate reservoirs because they have a great effect on reservoir parameters including porosity and permeability (Nelson, 2001; Rajabi *et al*., 2010). Generally, imaging tools are divided into two electrical and sonic categories which produce very high-resolution images for reservoir analysis (Schlumberger, 2003). In general, electrical images appear to be sensitive to variations in mineralogy, porosity, and fluid content. Acoustic image logs reveal a similar natural fracture population but do not reveal rock fabric owing to their lower resolution. However, due to their full coverage, acoustic images can reveal drilling-induced borehole wall tensile fractures, breakouts, and petal-centerline fractures (Tingay *et al.*, 2008; Nie *et al.*, 2013). The formation micro imager (FMI) tool has an azimuthal resolution of 192° capable of radial micro-resistivity measurements (Schlumberger, 1994). Electrical micro imager (EMI) electrode arrays are mounted on six independent arms providing excellent pad contact (Halliburton, 1996). These two tools cannot be used in the oil-based mud where oil base micro imager (OBMI) and ultrasonic borehole imager (UBI) are applied (Serra, 1989). Fractures diagnosis is not valuable by itself because fractures study is useful when their role in the system of porosity and permeability are determined (Martinez *et al.*, 2002; Brie, 1985). The present work is an attempt in order to determine the role of fractures and their effect on the reservoir properties as a vital subject in the carbonate reservoir. For this aim, VDL and RTF data coupled with image log interpretations were used in our study.

Geological setting of the studied area

The giant Marun oilfield is located in the Dezful Embayment, parallel to the general trend of the Zagros fold and trust belt (Fig. 1). It is one of the well-known oil provinces in the Middle East. The structural and stratigraphic features of the Dezful Embayment have been investigated since the middle of the last century (e.g., Haynes and McQuillan, 1974; Alavi, 2007). The Asmari Formation is the most important and proliferous reservoir in the SW of Iran (Fig. 2). In the Dezful Embayment, the formation was deposited from the Early Oligocene (Rupelian) to the Early Miocene (Burdigalian) in a NW-SE trend basin (Stocklin, 1968). Continued subsidence during the deposition of the Asmari Formation may be related to the latest stages of the closure of the Neo-Tethys, and the Asmari basin may represent the early stages of a foreland basin (Blanc *et al*., 2003; Wennberg *et al.*, 2007). Asmari deposition was followed by the deposition of Lower Fars group evaporates known as Gachsaran Formation (Aqrawi, 1993).The Asmari Formation comprises of fractured dolomites and limestones and, locally, the Ahwaz sandstone Member.

The source rock intervals were attributed to the Kazhdumi Formation, and the Gachsaran Formation is the cap rock. The Asmari Formation in this field is generally subdivided into three parts. The lower part consists of open-marine facies deposited mainly on a platform margin and its seaward slope and basinal equivalents (50-150 m). The middle and upper Asmari consists of relatively shallow-water facies (maximum 30-50 m) deposited in the platform-top settings. The Asmari Formation was divided into five main layers (1, 20, 30, 40, and 50) and 5 sub-layers (11, 28, 36.30, 40.80, 50 and 60) based on alternating siliciclastic and carbonate lithology (Gholipour, 1998). This classification is still used for the Asmari Formation in the Iranian National Oil Company (NIOC) and also in this study.

Methods and Materials

In this study, image logs as the main data and mud lost, RFT, and VDL as complimentary data are available in 11 studied wells (Fig. 4). Also, an isodip map was drawn for the Asmari Formation.

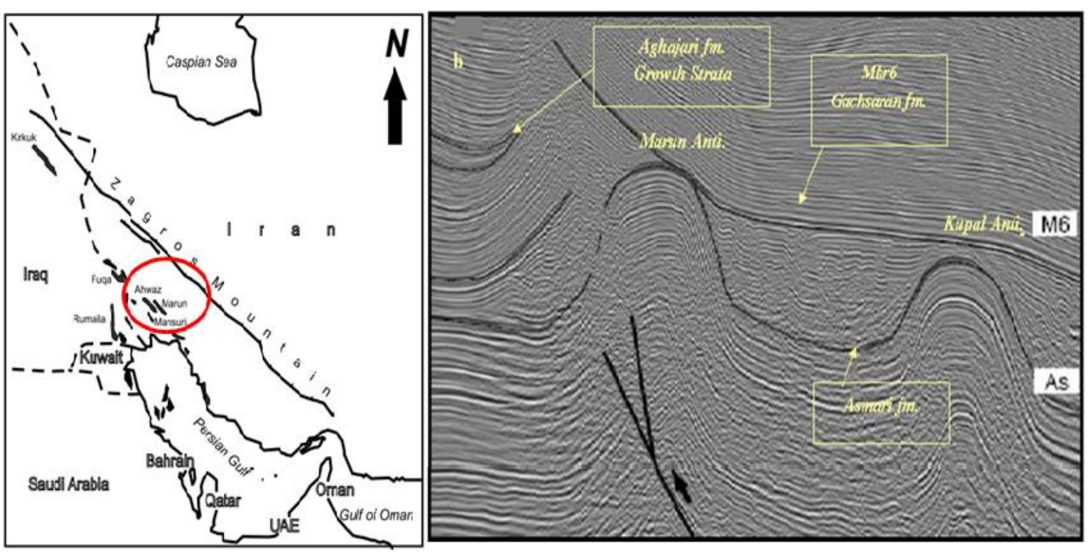

Figure 1. Location map of the Marun Field in southwestern Iran (Red circle) and 3D seimic section for marun anticlin and other adjacent fields provided by NISOC.

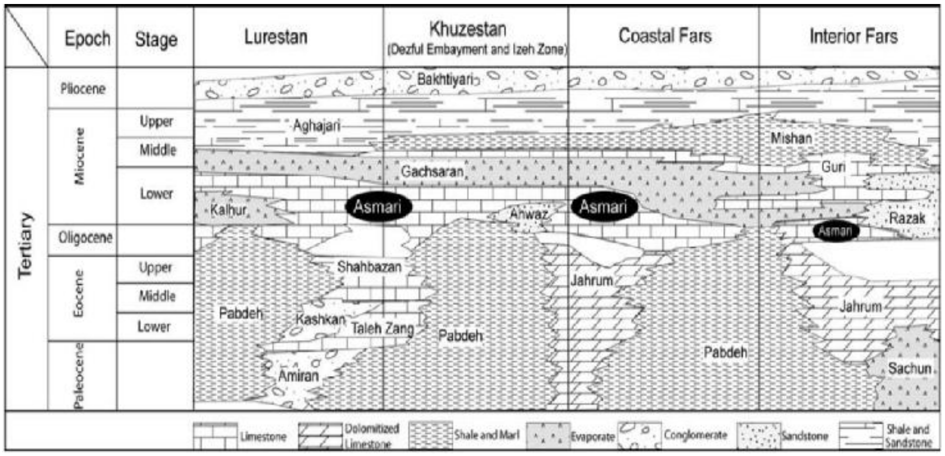

Figure 2. Cenozoic stratigraphic correlation chart of the Iranian Sector of the Zagros Basin, adopted from James and Wynd (1965).

The images are carefully described to characterize fractures and other geological features and finally the image results were correlated with other data. In this study, image logs were processed and interpreted by the Geoframe 4.5 software.

Image logs

There is a general consensus that image logs are the best method for fractures and structural study. Fractures are planar features with no apparent displacement of blocks along their planes (Fossen, 2010). Generally, they have a steep dip in tensional and wrench regimes. Their aperture may be open, tight (closed), or filled with some minerals (Schlumberger, 2005). On the image logs, fractures tend to occur as linear features that generally have a dip steeper than the structural dip (Fig. 3). Open fractures, in a clay free formation, have a conductive appearance on the images due to the invasion of their aperture with the conductive drilling mud. However, the mineralized or sealed fractures appear resistive if the filling material of their apertures is dense like calcite or anhydrite. In some cases, the fullest logs (PEF, RHOZ, Neutron and etc.) can also be very helpful for this kind of differentiation (Tokhmchi *et al.*, 2010; Ja'fari *et al.*, 2011). Between fracture parameters, the aperture has the greatest effect on reservoir properties especially permeability (Aghli *et al.*, 2014). The main types of geological structures are bedding and other sedimentary features. Generally, there are strong resistivity contrasts and the sedimentary dip information is of high quality where the formation is stratified. However, diagenetic processes have caused irregular bedding planes at few intervals and consequently hinder the precise determination of the structural dip (Fig. 3). There are some intervals within the Asmari sequence where the image log reveals relatively thinly bedded formations.

Complimentary methods

In this study, in order to achieve more accuracy, all image results were correlated with complimentary methods including VDL and RFT. The Velocity-Deviation Log is a log calculated by combining the sonic log with the neutron-porosity or density log, which provides a tool to obtain downhole information on the predominant pore type in carbonates. This log can also be used to trace the downhole distribution of diagenetic processes and to estimate trends in permeability. The main purpose of calculating the VDL log is creating an artificial log using the other petrophysical logs that can detect porous types and fractured zones (Figs. 6 , 7), because thay cannot be determined by Sonic, Neutron, and density logs in a carbonate reservoir (Guadagno & Nunziata, 1993). This log is calculated by first converting porosity-log data to a synthetic velocity log using a time-average equation. The difference between the real sonic log (DT) and the synthetic sonic log (DT_{syn}) can then be plotted as VDL. This log shows the difference between the real density wave values (Vp_{real}) and artificial density wave (Vp_{syn}) (Anselmetti and Eberli, 1999). A Repeat Formation Tester (RFT) is a wireline tool used to sample fluid formation and formation pressure. The tool is several tens of feet long with several chambers that hold several gallons of fluid. The tool is lowered into the well to a producing zone. A shoe is extended from the tool forcing it against the opposite wall of the well.

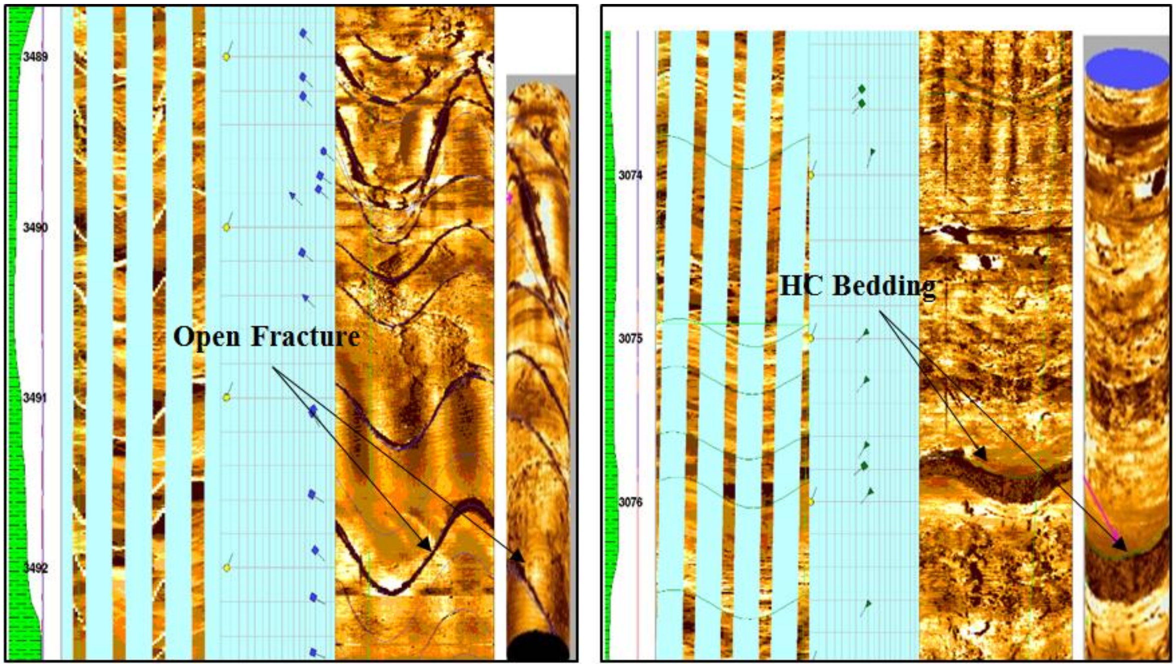

Figure 3. Fractures and bedding displayed on OBMI-UBI image log.

By opening a value, fluid is allowed to flow into the tool. As the fluid is flowing, the formation fluid pressure is also measured. RFT data is used for revealing the presence of the vertical relation. The pressure is used to calculate formation permeability, as well. The repeat formation tester is run on an open hole. In addition, mud lost data is used as an auxiliary method because it is usable for all fracture studies as available data in drilled wells.

Results and Discussion

After the analysis of electric and sonic image logs in the studied wells (Fig. 4), several features such as fractures, beddings, induced fractures, borehole breakouts, and stylolites were identified. Because of the importance of open fractures and bedding in this study (based on this study purpose), they were determined on image logs and fracture density was calculated for all wells. The results of each step are presented below:

Image Logs Results

Structural analysis and fractures density

In the Marun oilfield, the Asmari reservoir is a completely fractured reservoir. Fractured dip inclination varied from 30˚ to 80˚, their strike (orientation of the layer) was dominantly N130E and their azimuth (dip direction) varied from 0˚ to 360˚ from the north (Figs. 4 and 5). Both low and high confidence resistive fractures show a relatively large scattering in their dip azimuth and strike. The most fractures were in zones 1, 20, and 30 in the Asmari reservoir (Figs. 6 and 7). In some wells, zone 1 has 300 open fractures and zone 2 has 600 open fractures. In this field, considering the general pattern of fractures, it is evident that they are related to the folding and are mainly classified as longitudinal, transverse, and oblique. The main fracture set has the same orientation as the bedding which classifies it as a longitudinal set (Fig. 7). Strike in this set is almost N130E. The other fracture set is obliquely oriented relative to the bedding and is considered as an oblique set. Strikes in this set are N30E to N60E which can mostly be seen in the eastern section (Fig. 4). It is notable that the high density fractures in the central and eastern sections (well A and B, Fig. 4) are related to the axis re-circulation by the basement fault which is probably in the south section.

Structural dip description:

The electrical borehole images (OBMI) and ultra-sonic imager (UBI) clearly indicate layering/bedding throughout the logged interval (Fig. 2). Some layer/ bed contacts appear sharp and planar, while some have vague and uneven contacts (Darling, 2005; Saedi, 2010). These lines are easily correlated from pad to pad and are visible on static images and correspond to the surface or boundaries separating two beds of different lithology (Serra, 1989). So the dips computed from the first type of layer/bed boundaries are classified into High Confidence Bedding Dips (HC), and those from the uneven and vague boundaries are classified as Low Confidence Bedding Dips (LC).

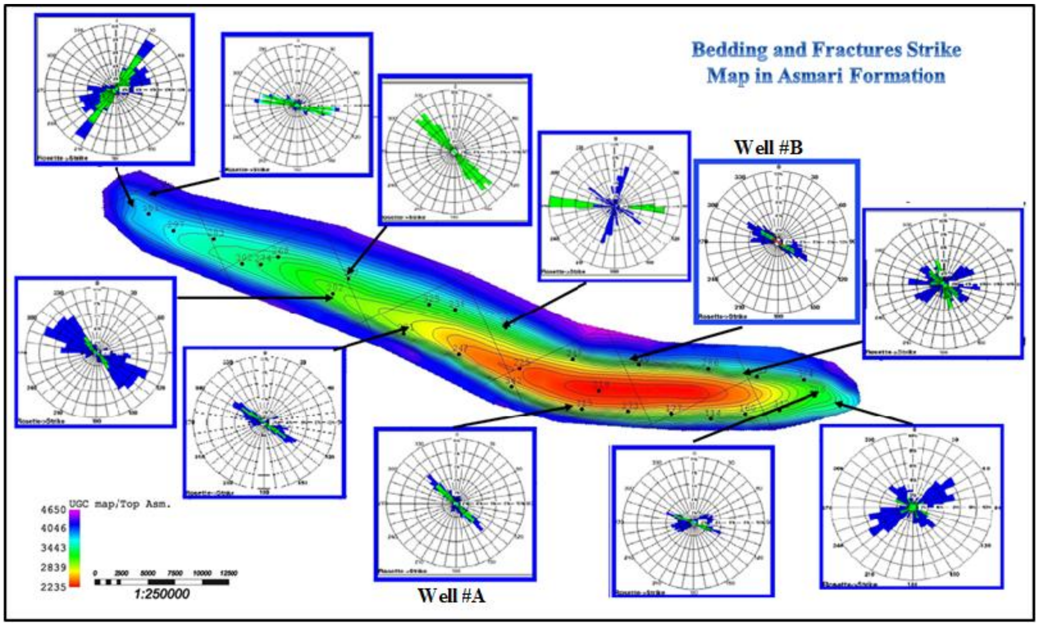

Figure 4. Represent of fracture and bedding strike in studied field using image logs results. As is evident, there are two fractures set in the Eastern section.

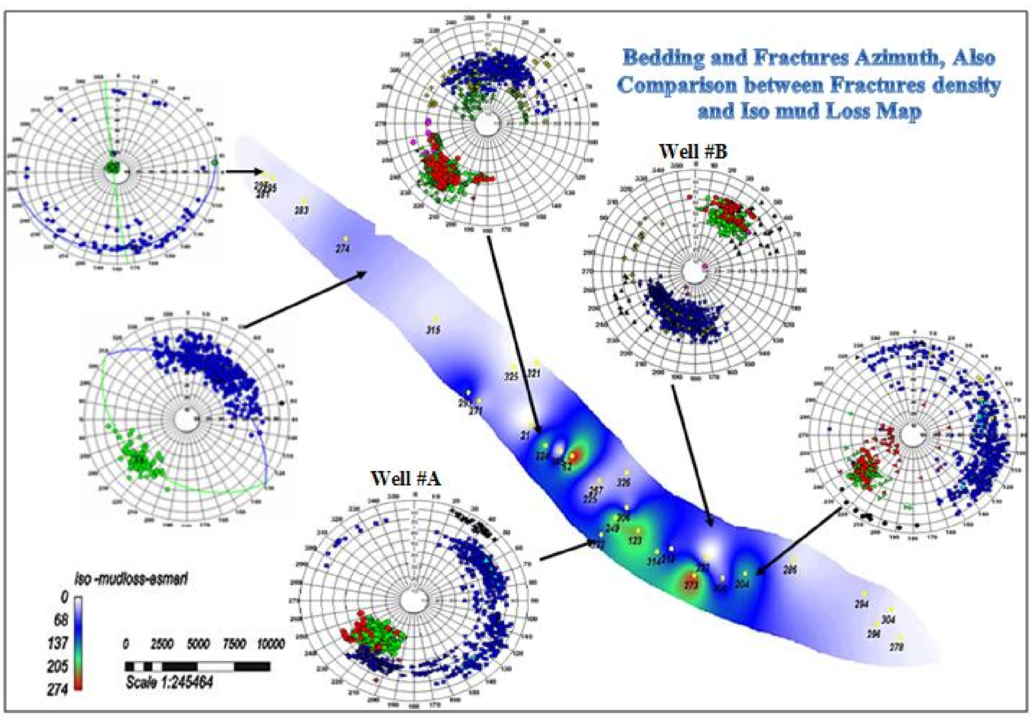

Figure 5. Represent of stereonet for fractures (blue points) and bedding (green pints) on Iso-mud loss map in the studied field. (Mud loss data represents center and eastern as fractured section in the studied field which show high correlation with images data)

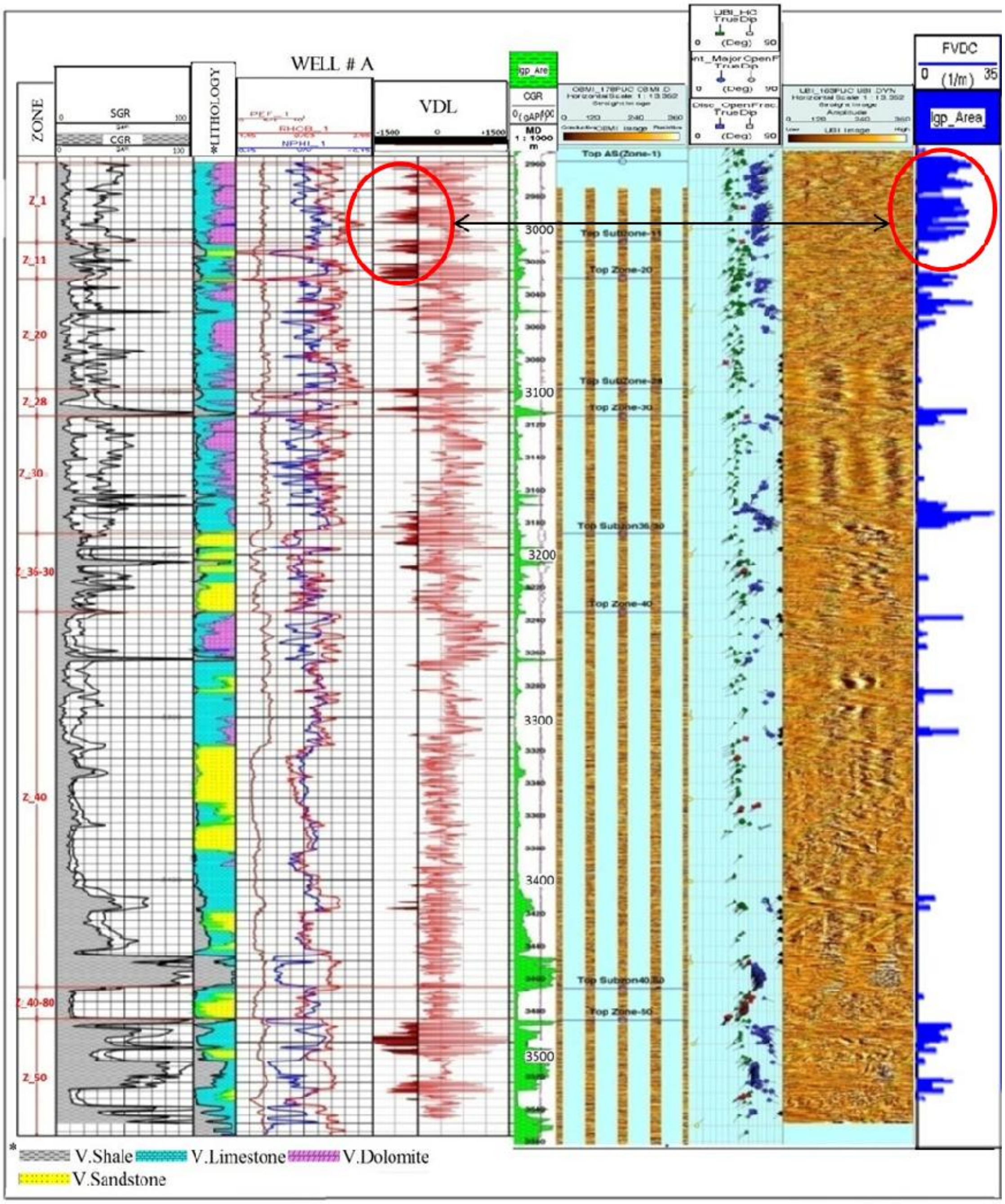

Figure 6. Results for Image log in the well A and its comparison with VDL log (Track 4)

Both classes of bedding dips compute nearly the same average and dominant dip magnitude and dip azimuth. Therefore, based on both types of bedding dips, a structural dip of 6 degrees N50W-S50E strike can be computed for the studied wells (Fig. 5). In this field, axis re-circulation has caused the bedding shift in the total area especially in the eastern section which in all reservoir parts fractures intercept the bedding.

Complimentary Methods Results

Velocity Deviation Log

In this study, for evaluating the dominant pores pattern and fractures detection, VDL log was drawn using Sonic and Neutron digital data for the Asmari reservoir in well A and B (Fig 4). Generally, there is an inverse relationship between porosity and velocity, so velocity decreases with increasing porosity (Wyllie *et al.*, 1956). Three zones are detected on a VDL log:

A) Zones with Positive Deviations: Indicating high porosity that is integrated in a framelike fabric of the rock (>+500 m/s).

B) Zones with ± Zero Deviations: Zones with small deviations (±500 m/s or less) represent interparticle, intercrystalline, or high microporosity.

C: Zones with Negative Deviations: Zones with abnormal deviations and very low velocity speed that can be caused by three factors (<-500 m/s):

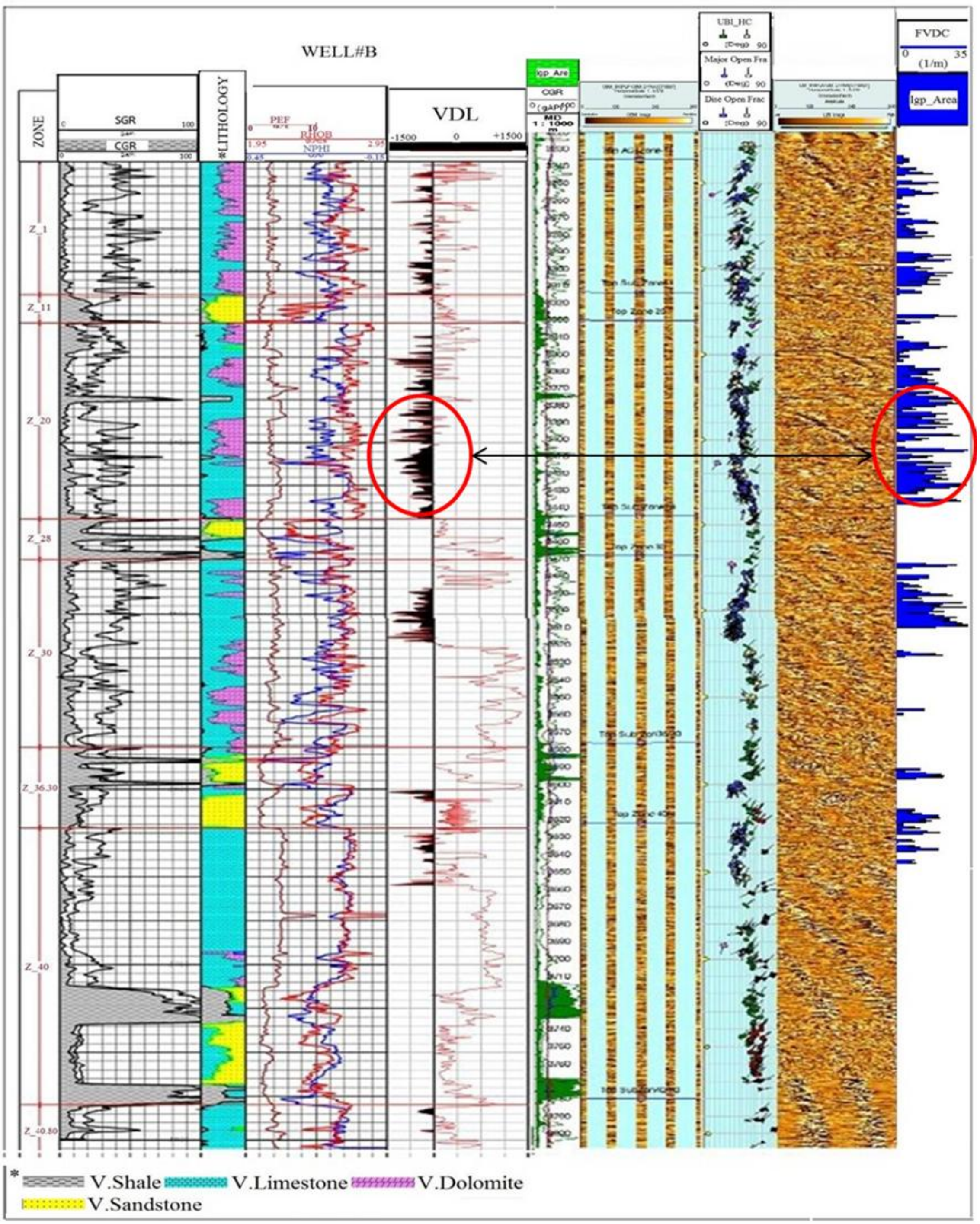

Figure 7. Results for Image log in the well B and its comparison with VDL log (Track 4)

1. Caving or irregularities of the borehole wall **2.** High content of free gas **3.** Despite the fact that fracture porosity has always been included in the secondary porosity which is an equivalent of very high velocity or positive deviations (Schlumberger, 1974), several studies have shown that fracturing decreases velocities on both a small scale (Gardner *et al.*, 1974) and a large scale (Guadagno & Nunziata, 1993). The larger scale fractures can be detected with logging tools and yield lower velocities than the undisturbed rock. As a result, fracturing produces negative deviations (Anselmetti & Eberli, 1999). As shown in Figures 6 and 7, VDL and fracture density log (FVDC) have high a correlation and VDL confirms the image result. The results of Velocity Deviation Log and images indicate that the production in the Asmari reservoir of this field is a combination of fractures and rock matrix.

Repeat Formation Test (RFT)
RFT is reliable data for the detection of fractures and their conductivity in the fractured reservoir.

RFT data is used for revealing the presence of the vertical relation and its pressure is used for the calculation of formation permeability. Presence of natural fractures could be determined by RFT data because this feature is the main cause for the vertical relation between reservoir zones (Fig. 8). RFT can determine shaly or dense zones which don't have the potential for open fractures.

RFT data for the western section indicate that reservoir zones have low vertical relation in the western section of the field due to the low fracture density (Fig. 9), but in the central and eastern sections, zones have high vertical relation because there is high fracture density (Fig. 6, 7).

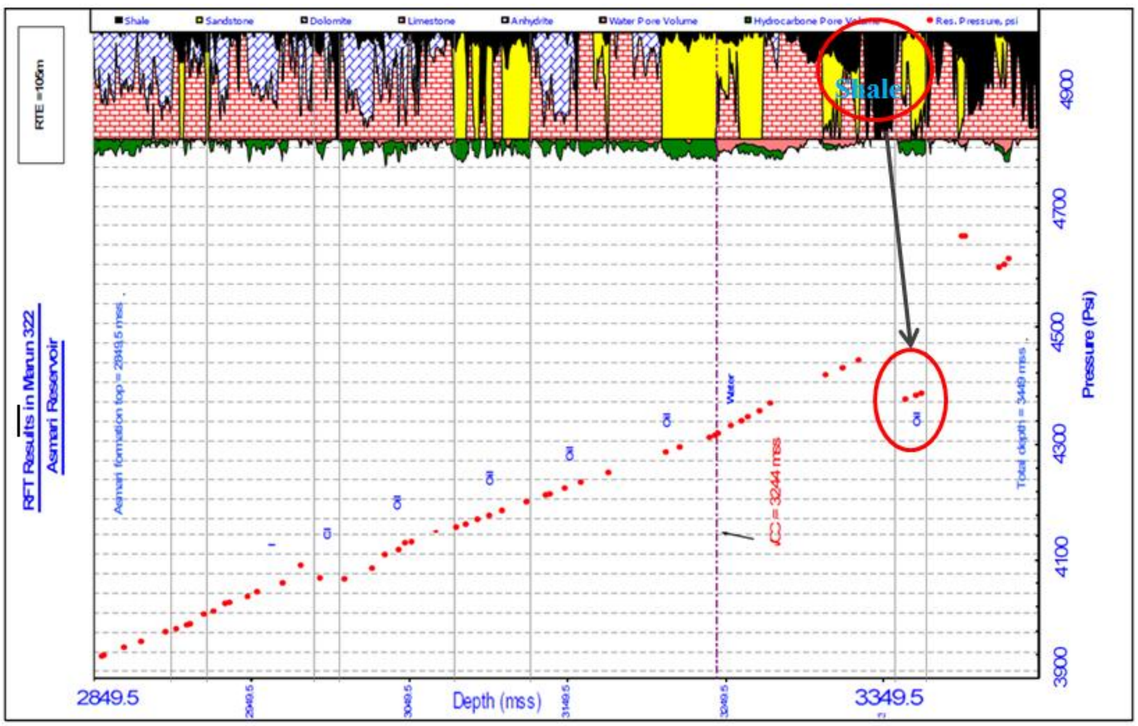

Figure 8. Repeat formation test (RFT) result for well A in studied field. Result show vertical relation in the upper horizons of the reservoir. Red circles indicate no conductivity between fractures due the presence of shale.

Mud Lost Data
Mud lost is a useful method for all fracture studies as available data in drilled wells. Additionally, it can be reliable for the determination of fractures and fault zones if correlated with other data. Complete or small losses of drilling fluid flowing from wellbore to the surrounding formations have been used to identify fracture zones in the past. It has been observed that the model fracture permeability values are in accord with mud lost data. In this field, mud lost data represent the central and eastern sections as fractured sections

that have high correlation with RFT and image results (Fig. 5).

Isodip Map

In this study, an isodip map is generated from the second derivative underground contour (UGC) to provide an overview on the fields' structure and the changes of axial bending. The first derivative of the isodip map represents the changes of bedding dip and bending layers which can identify areas with high potential for fractures (Roberts, 2001). The isodip map for the Asmari Formation in the studied well represents the southern edge as an area with high slope and curvature (Fig. 10) which has a high potential for fractures; this confirms the results of this study.

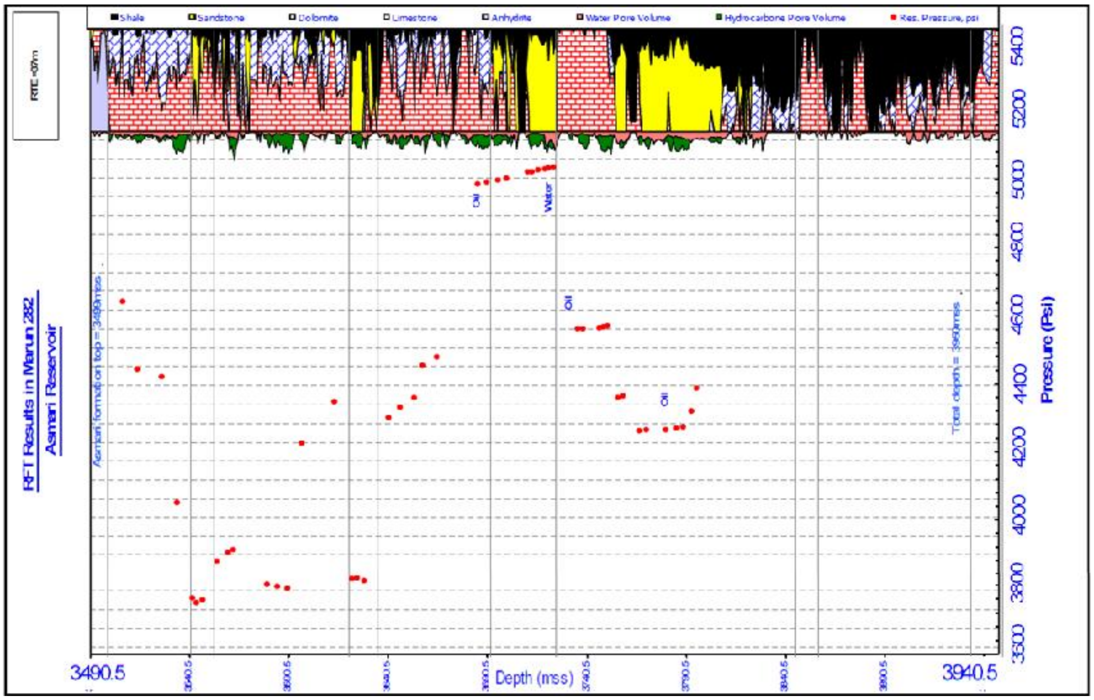

Figure 9. Display of RFT data for a well in western section. Results indicate low vertical relation due the low fracture density in this section.

Interpretation of Results

After all the study steps, there are two important questions; the first one is about the strike of fractures set in the studied field. Why are fractures in the central and eastern sections divided into two fracture sets while in the western section there is only one fracture set (Fig. 4)? In order to answer this question, in situ stress direction was determined for the studied field using image logs (Fig. 11). Borehole breakouts and induced fractures are two important features for the determination of in situ stress direction (Aghli, 2013). The identification and analysis of borehole breakouts as a technique for the in situ measurement of stress orientation and magnitude and identifying the orientation (azimuth) of both naturally occurring and induced fractures (hydro fractures) have received a great deal of attention in the past decade. Knowledge of the orientation of horizontal earth stresses derived from the analysis of borehole breakouts is important in the mentioned study area. Breakouts are typically conductive and poorly resolved because the wellbore fracturing and spalling associated with the results are in poor contact with the tool pads and the wellbore wall. Drilling-Induced Fractures (DIFs) typically develop as narrow sharply defined features that are sub-parallel or slightly inclined to the borehole axis in vertical wells and are generally not associated with significant borehole enlargements in the fracture direction. The stress concentration around a vertical borehole is at a minimum in the SH direction. Hence, DIFs develop approximately parallel to the SH orientation. Drilling-induced fractures can only be observed on image logs. DIFs typically become infiltrated by drilling mud (Tingay *et al.*, 2005).

Based on Figure 12, the stress direction in the eastern section of this oil field is therefore different from the western section and does not follow the Zagros general trend. This result confirms the hypothesis of the presence of a basement fault in the southern edge.

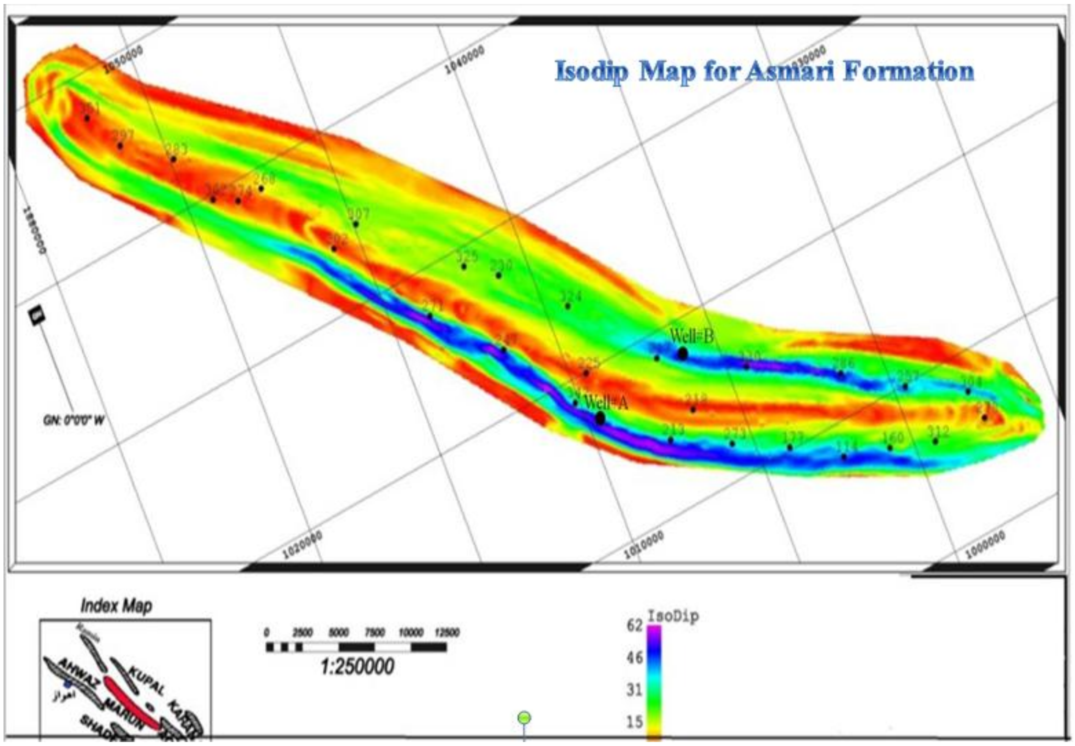

Figure 10. Isodip map for Asmari formation in the studied well

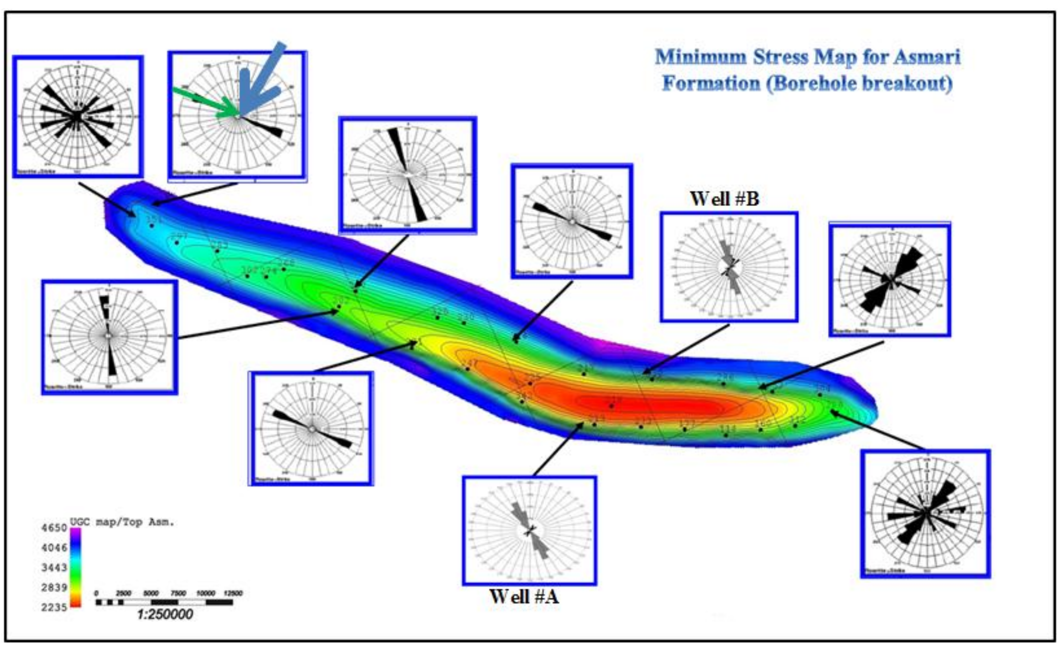

Figure11. Maximum and minimum main stresses direction in the studied field around wells (blue arrows indicate max stress and green arrows indicate min stress) using the borehole breakout. Stress directions different from eastern section. Therefore, eastern section does not follow Zagros trend.

The second question is about the effect of fractures on the reservoir properties. What is the role of fractures in the reservoir? For resolving this problem, VDL, RTF data, and other complimentary methods such as mud lost data were used. Based on VDL, we found that fractures are the most important features in the reservoir especially in the upper Asmari zones. On the other hand, production in this field is a combination of fractures and rock matrix. Also, RTF data demonstrate that in the western section of the studied field, reservoir zones have low vertical relation due to the low fracture density but in the central and eastern sections, zones have high vertical relation because there is high fracture density.

Conclusion

The main aim of this study was the systematic fractures analysis and the determination of their role in the reservoir properties of a carbonate Asmari Formation in Marun oilfield. Then, a comparison between image logs results and complimentary methods such as RFT, VDL, mud lost data, and isodip map has been drawn for more accuracy. Image logs interpretation shows that fracturing is present at a number of places. There are more than 600 open fractures in some zones which represent the Asmari Formation as a fractured reservoir. Between fracture sets, longitudinal patterns are dominant and often form open fractures. They are characterized by N60W-S60E and are mainly observed in the upper Asmari zones. Images indicate that the highest fracture density is in the zones 1, 20, and 30 of the Asmari reservoir that show high correlation with other data. RFT data reveal that reservoir zones have low vertical relation in the western section of the field due to the low fracture density. However, there is a relatively high vertical relation in the central and eastern sections owing to the high fracture density. VDL as a method for the detection of fracture zones shows high correlation with fracture density log (FVDC) and indicates that the production in the Asmari reservoir of this field can be the combination of fractures and rock matrix. Image logs also show a range of bedding dips from 20˚ in the northern limb to 30˚ in the southern limb with strikes ranging from 10˚ to 270˚N. Overall, fracture sets are ambiguous in this study because fracture sets in the eastern section were different from the western ones. In situ stress direction for the studied well indicates that the stress direction in the eastern section of this oilfield is different from the western section and does not follow the Zagros general trend. This point can confirm the hypothesis of the presence of a basement fault in the southern edge which could be created by other dominating fracture set. In this field, other auxiliary methods such as mud lost data and isodip map, in accordance with the other methods, demonstrate that the central and eastern parts are fractured.

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