Fracture and horizontal stress analysis of Dalan Formation using FMI image log in one of southwestern Iranian oil wells

Mohsen Ezati*[1], Bahman Soleimani[1], Mohamad Safarkhan Moazeni[1]

1- Shahid Chamran University of Ahvaz, Department of Earth Science, Faculty of Geology, Iran

* Corresponding Author: mohsenezati7@yahoo.com

Received: 15 November 2013 / Accepted: 26 December 2013 / Published online: 5 January 2014

Abstract

Recognition of relationship between the present day stress state and fractures is very important in fractured reservoirs. Fractures that are parallel or oblique to maximum horizontal stress have more tendencies to tensile deformation and tensile deformed fractures will be more permeable. The Dalan formation is one of the main gas reservoirs of Iran witch most of the production from this formation is related to the fractures. In this study fractures properties and maximum horizontal stress orientation was determined by using FMI image log. 20 borehole breakouts and 9 drilling induced fractures were used for stress direction determination. The total twenty recognized breakouts in the borehole are showing maximum horizontal stress toward N18.5°E. The quality ranking of the well for maximum horizontal stress determination is A by using breakouts and B by using induced fractures. For validation of calculated maximum horizontal stress from FMI, maximum horizontal stress was calculated by DSI too and two calculated maximum horizontal stress by FMI and DSI was compatible. Two sets of fractures were recognized in Dalan formation, set1 and set2, which are striking towards SE-NW and E-W respectively. Set1 and set2 fractures are parallel and oblique to the anticline axis respectively, therefore set1 fractures may be tensional fractures. Set1 fractures are perpendicular to maximum horizontal stress then this set may be closed in future and set2 fractures is oblique to maximum horizontal stress then shear deformation may causes of higher production for this set.

Keywords: Image Log, FMI, DSI, Drilling Induced Fractures, Maximum Horizontal Stress.

1–Introduction

Fracture concentration is function of the rock mineralogy, bedding thickness and structural position of the formation (Serra, 1989). Despite low porosity of fractures they are high permeable and in fractured reservoir large part of production is related to the fractures. So determination of fracture concentration, orientation, aperture and pattern is very important in fractured reservoirs.

Core analysis is one of the common approaches to find fractures in wellbore. In fractured reservoirs utilizing of core (for fracture determination) faces with some limitation; low recovery factor, lack of orientation and costs too much (Khoshbakht *et al*., 2009).

Image logs are kind of modern loges that can be used for detecting fractures crosscutting with the well. Electric imaging tools (e.g. FMI) use different electrical properties of rocks and geological features to make an electric image from the well (Khoshbakht *et al*., 2012). Structural features that can be recognized in image log are natural fractures that induce fractures, borehole breakouts, bedding plane and etc .

Recognizing of stress direction is very important in exploration and production of the oil and it is effective on well stability, flow unit patterns, fluid flow in fractured reservoirs, cap rock failure and fault reactivation (Sibson, 1996). Natural fractures that are parallel to the Shmax- Maximum Horizontal Stress- (or oblique to that) are capable to tensile or shear deformation and mostly observed that these types of fractures are more permeable (Sibson, 1996).

2– Geological setting

Zagros fold-thrust belt extends about 2000 km from southeastern Turkey through northern Syria and Iraq to western and southern Iran (Alavi, 2004). Zagros basin is a part of the Tethys Ocean and is one of the most important petroleum basins in all over the world (Alavi, 1994). Folding process of Zagros basin occurred in Miocene and Pliocene and continued until now which formed long anticlines (Mottie, 1995). The studied well is located in Dezful embayment of Zagros basin in south west of Iran (Fig. 1).

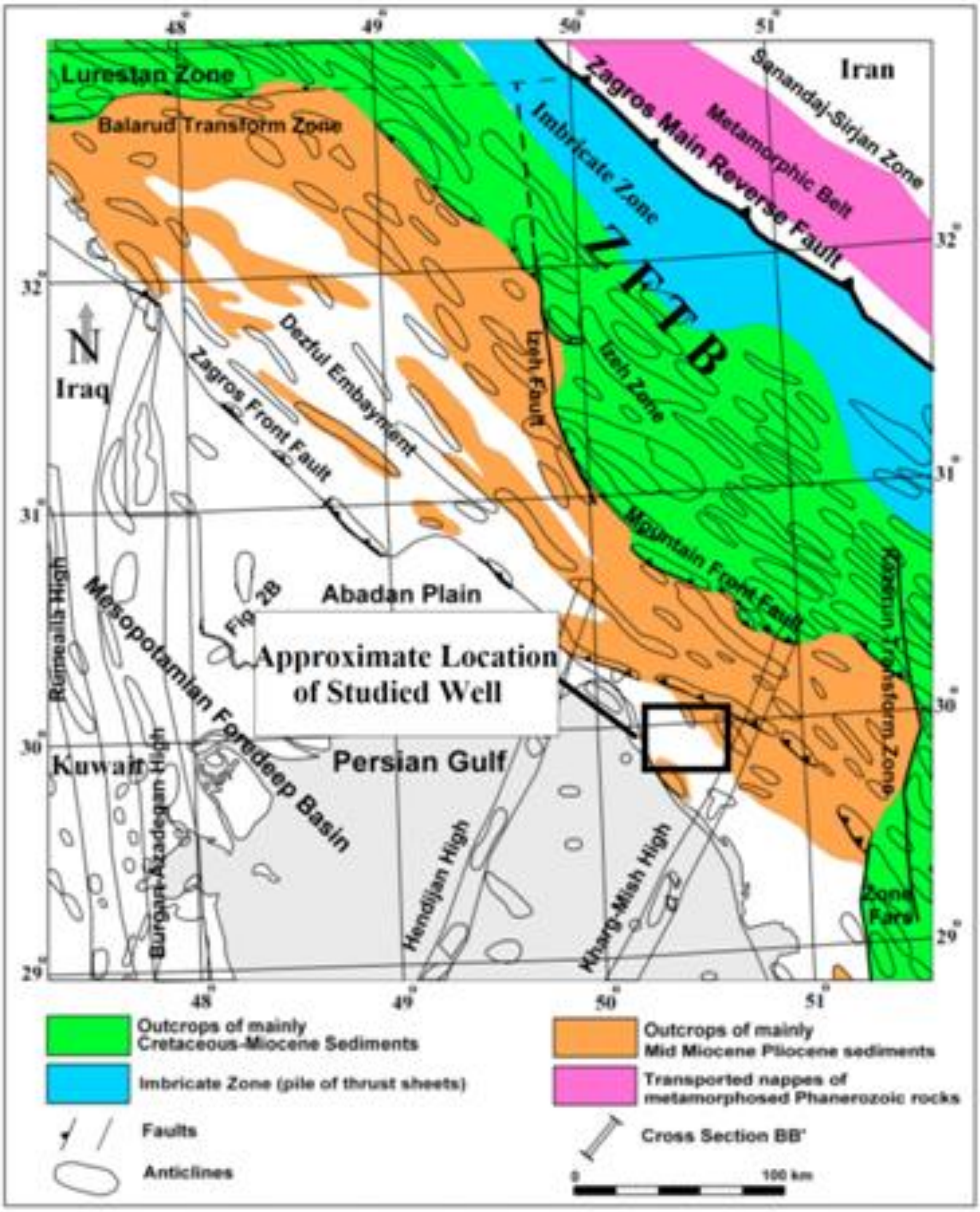

Figure 1) The approximate location of studied well on the map. The well is somewhere in the square (modified from Abdollahie Fard et al., 2006).

Dalan Formation is related to carbonate facies of Upper Premian and the type section of this formation is located at Kohe-e-Siah well #1 with 748 meters width (Aghanabati, 2004). Dalan Formation age is Gubergendinian to Dorashamian (Aghanabati, 2004). Lower contact is with Faraghan Formation and upper contact is with Kangan Formation. Dalan Formation has three members (Fig. 2); Upper Dalan Member (Carbonate), Nar Member (Anhydrite) and Lower Dalan Member (Carbonate).

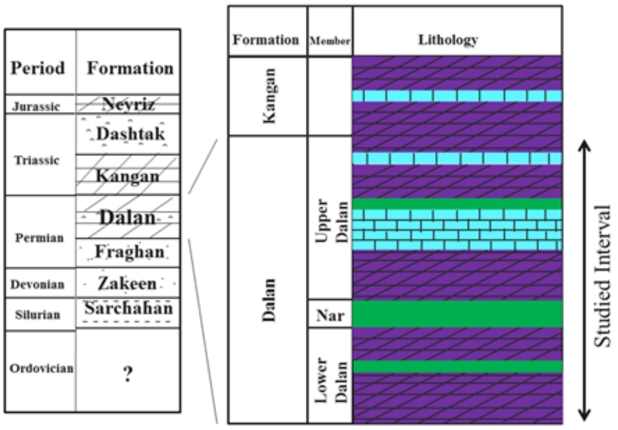

Figure 2) Dalan Formation position in geological column.

3– Methods

As FMI tools are electrical, it can be used in water-based (conductive) drilling mud. In drilling process, hydrostatic pressure of drilling mud is higher than formation pressure then mud can penetrate in open fractures. High conductivity of penetrated water-based mud causes open fractures to be black in image log. Each electrode in FMI tool measures electrical properties of formation separately.

Breakout happens when the circumferential stress concentration is more than compressional strengths of the rock (Bell and Gough, 1979). Maximum circumferential stress has same directional with breakouts and breakouts are perpendicular to SHmax (Kirsch, 1898). Induced fracture happens when the stress concentration around the well is more than tensional strengths of the rock (Aadnoy, 1990). Minimum circumferential stress direction is parallel to induced fractures and these fractures are created in SHmax direction (Tingay *et al*., 2008; Rajabi *et al*., 2010). Induced fracture has some characters that make it different from the natural fracture, for example: parallel to the wellbore (in vertical wells), coexisted with breakouts and low contrast with the surrounding rock in image log. The main character of induced fracture that makes it recognizable from natural fracture is the angle (parallel to the wellbore or high angle).

DSI is a modern sonic log that makes shear waves to recognize petrophysical properties of the rock. In deviatoric stresses condition, fractures that are parallel to SHmax remain open and fractures perpendicular to SHmax will be closed. In this medium fast shear wave moves to open fractures direction (SHmax direction) and slow shear wave moves to closed fractures direction (SHmax direction).

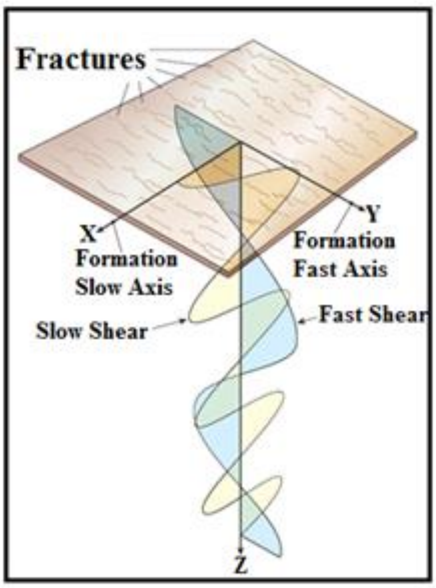

***Figure 3)** Separation of shear wave into two components in anisotropic formation (Brie et al., 1998).*

Fast shear wave direction can be determined as AZIM-FAST log, after anisotropy determination for the reservoir, so AZIM-FAST log shows higher compaction direction in rock (Fig. 3). As the anisotropy direction of achieved row data is not parallel with formation anisotropy direction, axis of the tools can be paralleled with the formation anisotropy direction by using Alford Rotation method.

4– Results and Discussion

In this study of natural fractures, induced fractures and breakouts was surveyed in Dalan Formation. Also fracture sets and their relation with the regional structures was discussed. Open fractures are more attend able for the reservoir engineers thus depth and character determination of this kind of fractures is very important. SHmax direction was determined by using breakouts, induced fractures and DSI sonic log.

4.1– Natural Fractures

Total of 1448 natural fractures have been counted in the borehole that all of them were open fractures. Closed fracture was not seen in the borehole. Two sets of fractures was recognized, set1 and set2 which are striking towards SE-NW and E-W respectively (**Fig. 4**).

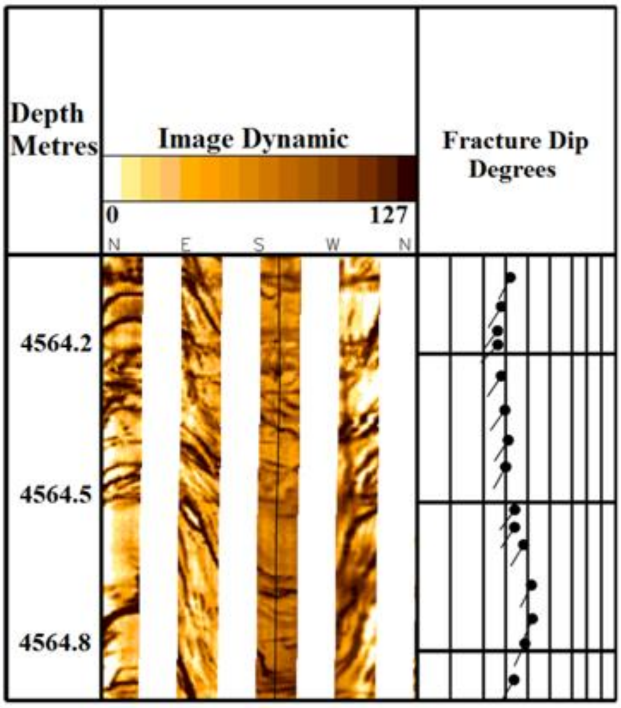

Figure 4*) Set1 fractures in image log.*

Set1 fractures frequency is more than set2 in the borehole. Stereonet and rose diagram was built for three members of the Dalan Formation. Two mentioned sets of fractures exist in all members. Set2 is more abundant in Upper Dalan member and fracture distribution in this member is more dispersed than other members. Majority of Nar member fractures (fractures cannot penetrate in anhydrite layers because of ductile nature of evaporates and this fractures are exist in dolomite interlayers) belong to set1 and fractures with dispersed distribution are less than other members. In Lower Dalan more of the fractures belong to set1 but presence of set2 fractures is not negligible (Fig. 5).

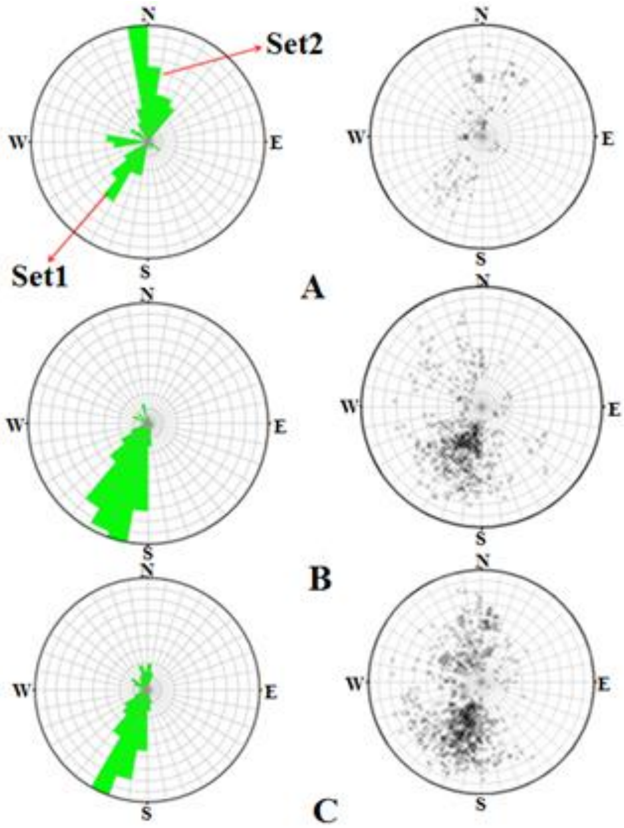

Figure 5) A: stereonet (upper hemisphere in Schmidt net) and rose diagram (dip direction azimuth) for Upper Dalan Member; B: stereonet and rose diagram for Nar Member; C: stereonet and rose diagram for Lower Dalan Member.

With notice to the UGC map of the anticline, set1 fractures are parallel to the anticline axis and set2 fractures are oblique to that (Fig. 6).

Set1 fractures is related to tension fractures because this fractures are parallel to anticline axis and set2 fractures may related to conjugate fractures but there is no fracture in the other side to complete this conjugation. Set2 should be related to fault activity in southern limb of anticline due to more dispersion for this set.

Set1 fractures may be closed in future due to they are perpendicular to the SHmax and set2 fractures may have more permeability due to oblique angle to SHmax (shear deformation may happens for this fractures).

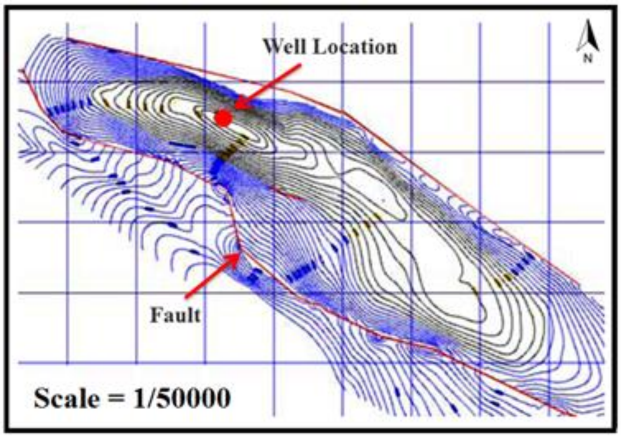

Figure 6) UGC map of Dalan Formation and well location on it.

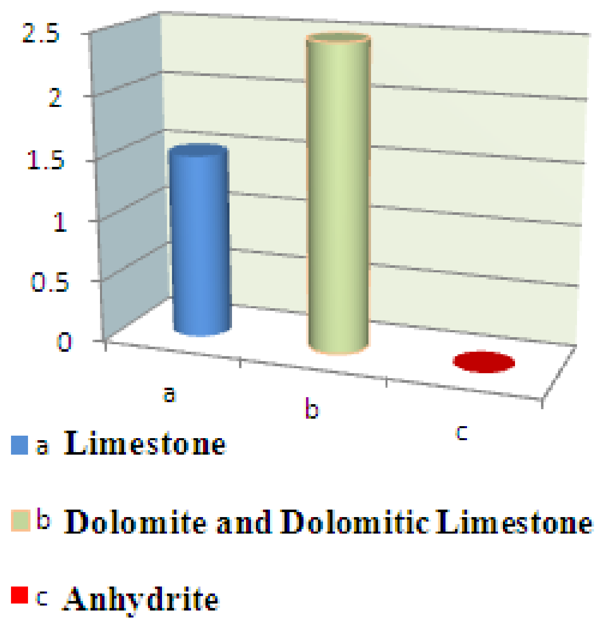

Figure 7) Fracture concentration in different lithologies. As can be seen in the bar chart dolomite and dolomitic limestone lithology shows more fracture concentration in the well

Figure 7 shows fracture concentration in different lithologies of the well. Dolomite and Dolomitic Limestone lithologies have higher fracture concentration due to dolomite has more brittle tendency than limestone. High natural fracture concentration in the well (1448 fractures in 750 meters studied interval) is related to majority of Dolomite and Dolomitic Limestone (more than 60 percent) in the well and position of the well that drilled in crest of the anticline (Fig. 6).

4.2– Breakouts

Figure 8 shows one of recognized breakouts in the borehole. Total twenty breakouts in the wellbore were recognized and mean of azimuth is 108.5° and mean of dip angle is 78° (Table 1). In vertical well breakouts are commonly parallel to the wellbore (Sibson, 1996) but in this case they are built oblique to the well. Tilting of the breakouts is related to the directional drilling (approximately 4° vertical deviation) and angular horizontal stress around the well.

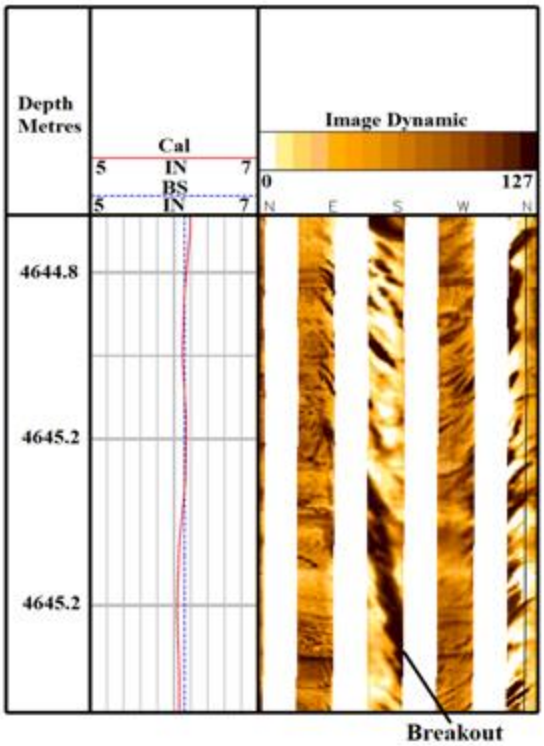

Figure 8) One of the recognized breakouts in image log of the borehole. The tracks are depth, Bit Size – Caliper and dynamic image log left to right respectively. In middle track Bit Size and Caliper logs are coincident approximately but in lower part of the track Caliper is less than Bit Size that causes mud cake creation in this part.

Table 1) List of the used Interpreted Features for SHmax Orientation determination by using FMI. BO and DIF are borehole breakout and drilling induced fracture abbreviations respectively.

N0	Type of Interpreted Features	Borehole Deviation (degree)	Orientation of Features (azimuth)	SHmax Orientation
1	BO	1.9	97	7
2	BO	1.9	94	4
3	BO	1.9	96	6
4	BO	1.9	91	1
5	BO	2.7	115	25
6	BO	2.7	115	25
7	BO	2.7	115	25
8	BO	2.7	126	36
9	BO	2.7	111	21
10	BO	3.9	108	18
11	BO	3.9	107	17
12	BO	3.9	113	23
13	BO	3.9	103	13
14	BO	4.6	98	8
15	BO	4.6	104	14
16	BO	4.6	111	21
17	BO	5	123	33
18	BO	5	124	34
19	BO	5	120	30
20	BO	5	99	9
21	DIF	2.7	26	26
22	DIF	4.6	39	39
23	DIF	4.6	41	41
24	DIF	5	0	0
25	DIF	5	3	3
26	DIF	5	8	8
27	DIF	5	6	6
28	DIF	5	3	3
29	DIF	5	7	7

Total length of the recognized breakouts was 42 meters and standard deviation of the breakouts strike was 10.53°. Length weighted and number weighted SHmax directions from breakouts are 21.3 and 18.5 respectively that implicates there is some long breakouts that have bigger azimuth than average. In World Stress Map (WSM) classification for horizontal stress direction determination, the quality ranking of the well for SHmax determination by using breakouts is A (Table 2).

4.3– Induced Fractures

9 induced fractures were recognized in the well (Fig. 9). Length weighted and number weighted directions of SHmax form induced fractures are 24.6 and 14.77 respectively. The average of the dip is 70°. Induced fractures like breakouts commonly are parallel to vertical well (Sibson, 1996) but because of above reasons they are not vertical. Induced fractures and breakouts are perpendicular to each other and their orientations show SHmax and SHmin (Minimum Horizontal Stress) respectively. In WSM classification for horizontal stress direction determination, the quality ranking of the well for SHmax determination by using induced fractures is B (Table 2).

Table 2) Quality Ranking determination from BOs and DIFs properties.

Type of Features	Total number	Total Length (m)	Mean SHmax Orientation (length weighted)	Mean SHmax Orientation (number weighted)	Standard Deviation	Quality Ranking
Borehole Breakout	20	42	21.3	18.5	10.53	A
Drilling Induced Fracture	9	11	24.6	14.77	16.12	B

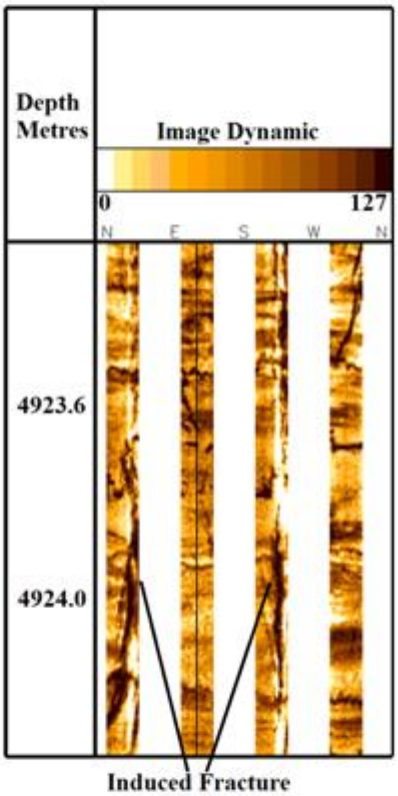

Figure 9) Induced fracture in image log.

4.4– DSI SHmax

As DSI tool rotates around its axis while logging process, its rotation was removed from data. Directions that slow and fast waves moved perpendicular to each other was recognized and AZIM fast was made by using of Alford

Rotation method. The advantage of SHmax direction determination by using DSI is that it can be determined continuously in borehole but FMI image can be used for SHmax determination only in induced fractures and breakout existed intervals of borehole.

Figure 10 shows SHmax derived from the DSI (that achieved from total studied interval of the well), breakouts and induced fractures rose diagram. The average of DSI SHmax in the borehole is toward N30E.

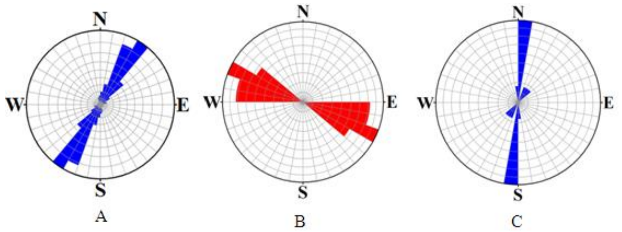

Figure 10) A-DSI SHmax rose diagram B-Breakouts rose diagram C- Induced fractures rose diagram.

3– Conclusions

More fractures will be cross-cut the well with directional drilling to NE-SW, because this direction is perpendicular to most of fractures. Directional drilling in NE-SW direction will make the borehole more stable too because of SHmax direction is NE-SW.

Dolomite and dolomitic limestone lithologies shows more fracture concentration in the borehole then perforation and directional drilling should be regarded in these lithology intervals of the borehole.

Studied well shows NW-SE SHmax direction that is compatible with World Stress Map SHmax direction in that region.

Two SHmax calculated by FMI (induced fractures and breakouts) and DSI are compatible. DSI SHmax was reached from total studied interval and FMI SHmax was reached using some breakouts and induced fractures then slight difference (approximately 10°) between them may be relate to different covering of the wellbore.

The quality ranking of the well for SHmax determination is A by using breakouts and B by using induced fractures then using breakouts for that is more reliable.

Acknowledgments:

The authors would like to thank Dr. M. Rajabi and Dr. B. Habibnia for their kind and careful comments that made the manuscript improved. They also wish to thank Tarbiat Modares University for providing the possibility of conducting this research.

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