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In-situ stress analysis using image logs

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ABSTRACT

In the reservoirs, rocks are affected by three principal stresses (σ_1=maximum principal stress, σ_2=intermediate principal stress and σ_3=minimum principal stress) due to the overlying strata and tectonic region, but drilling a new well will create in-situ stresses (σ_{hmax}=maximum horizontal in-situ stress, σ_{hint}=intermediate horizontal in-situ stress and σ_{hmin}=minimum horizontal in-situ stress) that will disrupt the stress system in area around the well. Analyzing this new set of stresses is very important, because during the new drilling operation the rock strength around the well will be changed that can affect the other drilling operations and also the other operations, such as hydraulic fracturing, EOR mechanisms, and so on. In this paper, we will find the in-situ stresses direction in Gachsaran field, and also by doing this case study and showing the appropriate examples of log interpretation, we will introduce this technology. This job shows that the maximum horizontal in-situ stress direction of this field is NE-SW, and the minimum horizontal in-situ stress direction is NW-SE; for two wells in this field, the direction of in-situ stresses are quite different from the other wells that it might be the effect of fault, fold and diapirism on in-situ stresses.

KEYWORDS

Principal stresses;
In-situ stresses;
Drilling operation;
Image log interpretation;
Drilling induced fractures;
Borehole breakouts.

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 the Asmari reservoir, the Pabdeh reservoir, the Gurpi reservoir and the other reservoirs Figure 2[1].

Image log technology is a new technology that can characterize the oil and gas reservoirs in many cases such as structural analysis, fracture characterization, fault interpretation and in-situ stress analysis[3]. These applications are still unknown to some researchers that are interested in learning the way that we can drive the in-situ stresses direction from image logs, so in this job using a case study and numbers of valuable log interpretation we will explain this process completely.

In this work, 10 wells located inGachsaran oil field will be selected, and the in-situ stress analysis will be done in these wells by using the image logs and the other geological logs interpretation. We will

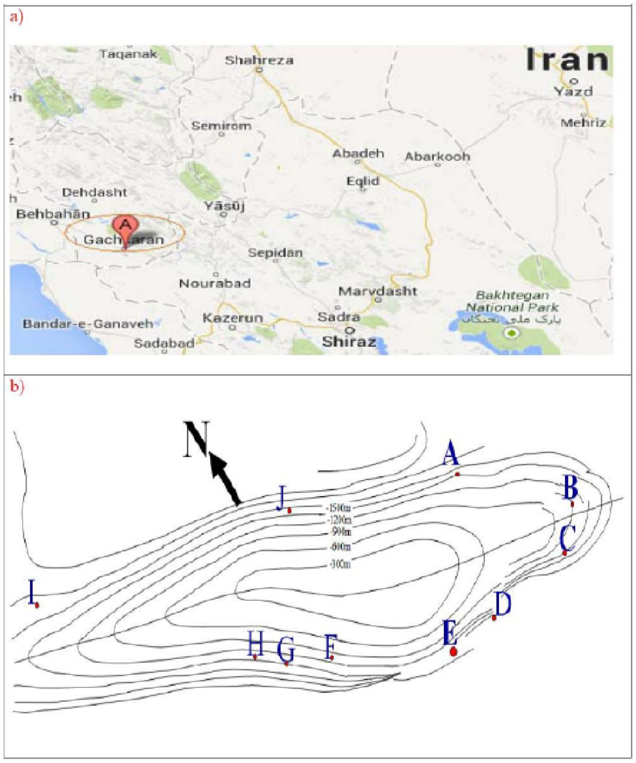

Figure 1 : (a) Location of theGachsaranfield[2]; (b) UGC map of theGachsaran field and the studied wells

do the in-situ stress analysis 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 in-situ stress analysis very well; by interpreting the image logs, we can find out both the direction of drilling induced fractures that is parallel to the maximum horizontal in-situ stress direction and the direction of borehole breakouts that is parallel to the minimum horizontal in-situ stress direction[4,5].

MATERIAL AND METHODS

The main data for this job are the image log data including the Formation Micro Scanner (FMS), Oil-Base-Mud Imaging (OBMI), Formation Micro Imager (FMI) and the Ultrasonic Borehole Imager (UBI). In this work, 10 wells (Wells number GS-A, GS-B, GS-C, GS-D, GS-E, GS-F, GS-G, GS-H, GS-I and GS-G), located in the Gachsaran oil field, will be studied.

Maximum horizontal in-situ stress (σ_{hmax}) direction is same as induced drilling fracture direction, and minimum horizontal in-situ stress ($\sigma_{hmin)}$ direction is same as borehole breakout direction; both drilling induced fractures and borehole breakouts are created during the drilling operation[6,7].

Drilling induced fracture and borehole breakout are different in images; the drilling induced fracture is in the form of a fracture seen by the images, oriented at 180 degrees from each side of the well, but borehole breakout is in the form of borehole elongation on the orthogonal calipers and as long dark regions on the images that are 180 degrees apart Figure 3.

THEORY

The borehole breakouts are due to the hoop stress that this stress causes shear failure in the borehole, and the drilling induced fractures are due to the radial stress and this stress causes the tensile failure in borehole. By finding out the direction of induced drilling fractures and borehole breakouts from the image logs, we can find the direction of in-situ stresses[4,5,7].

In wellbore there are always hoop stress and radial stress; they cause drilling induced fracture and boreahole breakout, but it's depend on the rock strength in any part of wellbore that which one will happen. If the rock strength is low the drilling fluid will wash the rock and borehole breakouts will happen, but if the rock strength is high the drilling fluid will cause drilling induced fractures (hydraulic fractures)(Figure 4)[6,7].

RESULTS

In-situ stress analysis for the well number GS-A

The FMI images showing borehole breakouts on the images facing northwest and southeast sides of the borehole. Thus they indicate WNW-ESE trending elliptical borehole breakouts that are aligned with σ_{hmin} Figure 5. In this well the direction of σ_{hmax} is NNE-SSW.

In-situ stress analysis for the well number GS-B

The amplitude and the radii images of UBI show

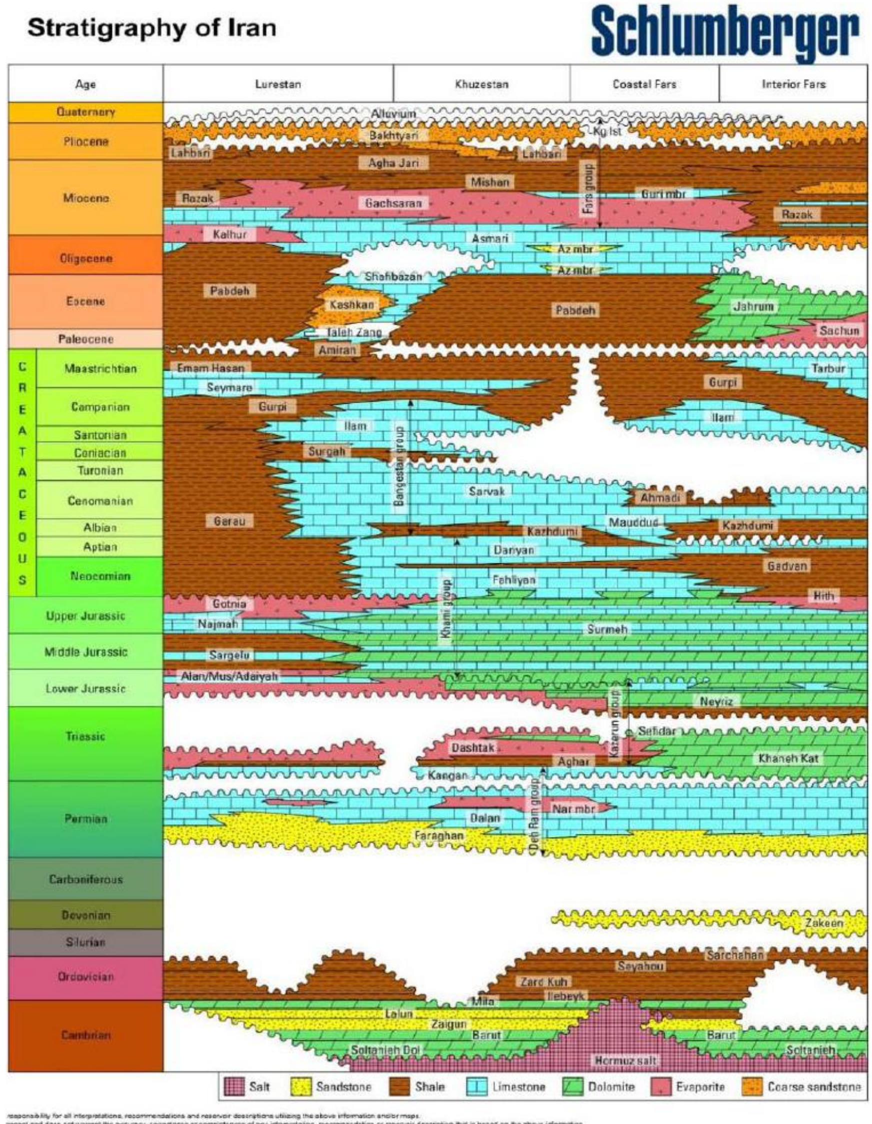

Figure 2 : Picture showing the Gachsaran field overlying the Asmari, Pabdeh, Gurpi and other reservoirs, and stratigraphic nomenclature of rock units and age relationships in the Zagros basin

elliptical borehole breakouts in many zones. In some places only the first stage of borehole breakouts in the form of conjugate shear fractures was identified. The cross-sectional slices of borehole radii across such intervals indicate the NE-SW orientation for the longer axis of the borehole breakouts Figure 6. It indicates the NE-SW orientation for σ_{hmin} and the NW-SE orientation forσ_{hmax}.

In-situ stress analysis for the well number GS-C

A cross-sectional slice of the borehole radii at 2512m and a spiral plot / down-looking pipe view across the 2512m-2512.3m depth indicate the WNW-ESE orientation for the longer axis of the borehole breakouts Figure 7. Such breakouts represent shear failure of the formation exposed to the wellbore. The borehole breakouts indicate the WNW-ESE orientation for σ_{hmin} and the NNE-SSW orientation for σ_{hmax}.

In-situ stress analysis for the well number GS-D

The amplitude and radii images of UBI show elliptical borehole breakouts in most part of the borehole. A composite plot of the borehole breakout's azimuth and their magnitude indicates change in the orientation of the longer axis of the borehole breakouts. In the zones of the borehole deviation, the dominant orientation for their longer axis is the

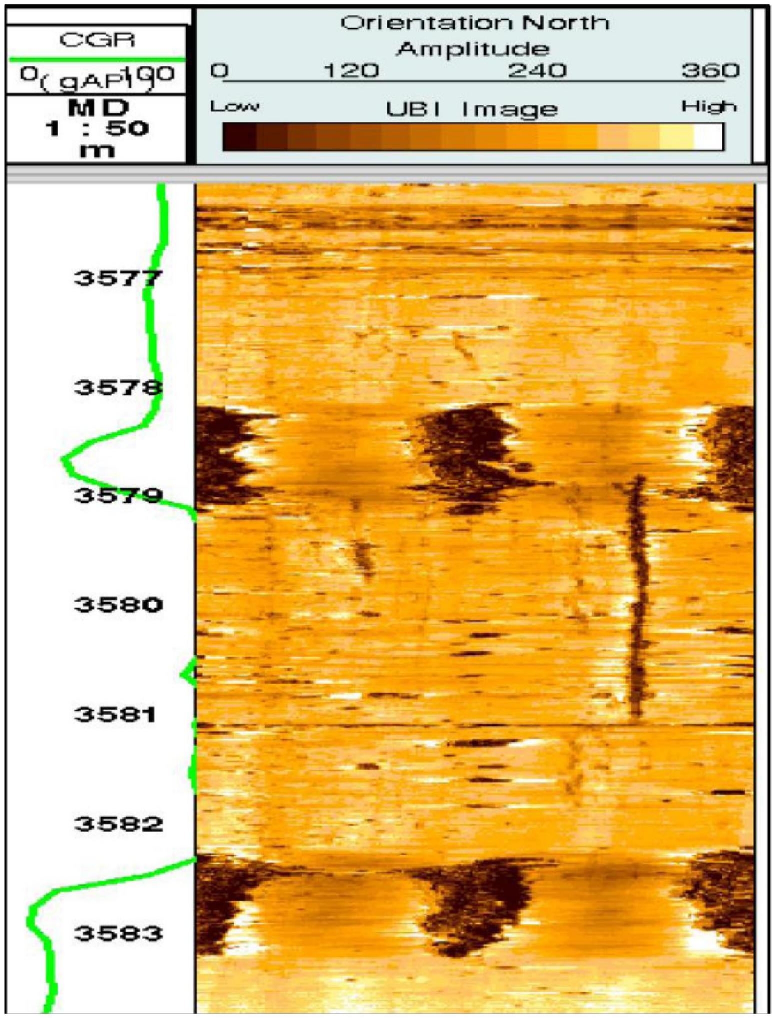

Figure 3 : The UBI image showing borehole breakouts and drilling induced fractures; the thin dark color region is drilling induced fracture, and the dark wide regions are borehole breakouts

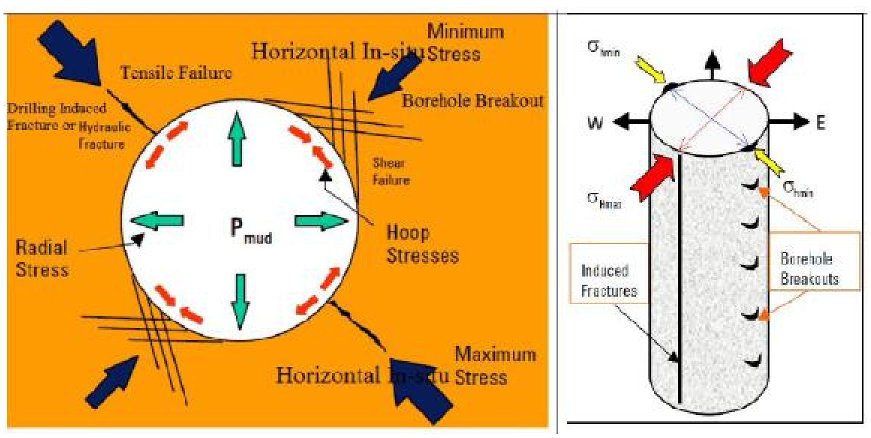

Figure 4 : schematic pictures of the radial stress, tensile failure, drilling induced fracture (hydraulic fracture), maximum horizontal stress, hoop stress, shear failure, borehole breakout and minimum horizontal stress

NE-SW direction Figure 8.

Their orientation in the zones (For example, the lower half of the well trajectory) of a well's deviation greater than 20 degrees does not reflect the true orientation of borehole breakouts. A correction needs to be applied to get the true orientation of borehole breakouts in such situations. Such breakouts represent the shear failure of the formation exposed to the

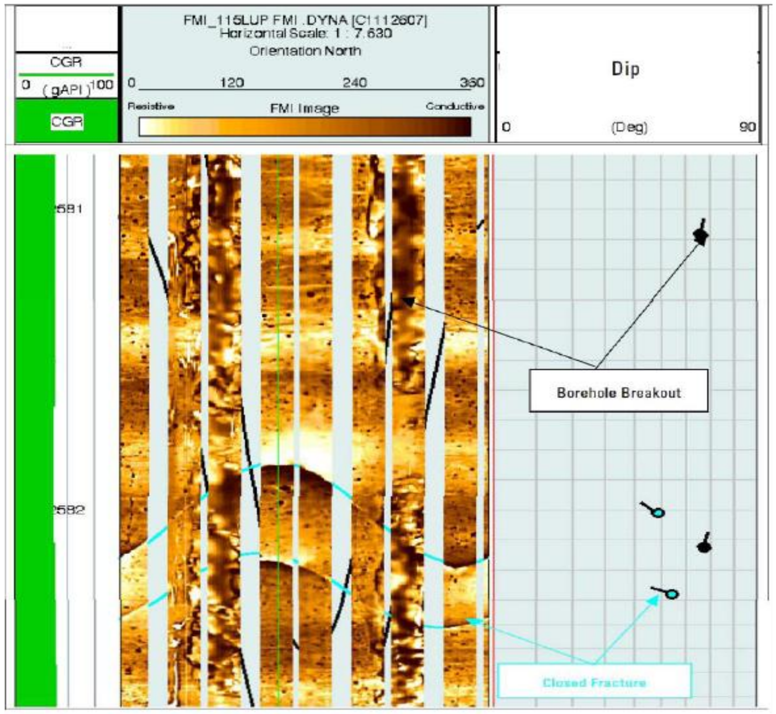

Figure 5 : In well GS-A, the FMI images showing borehole breakouts on the images

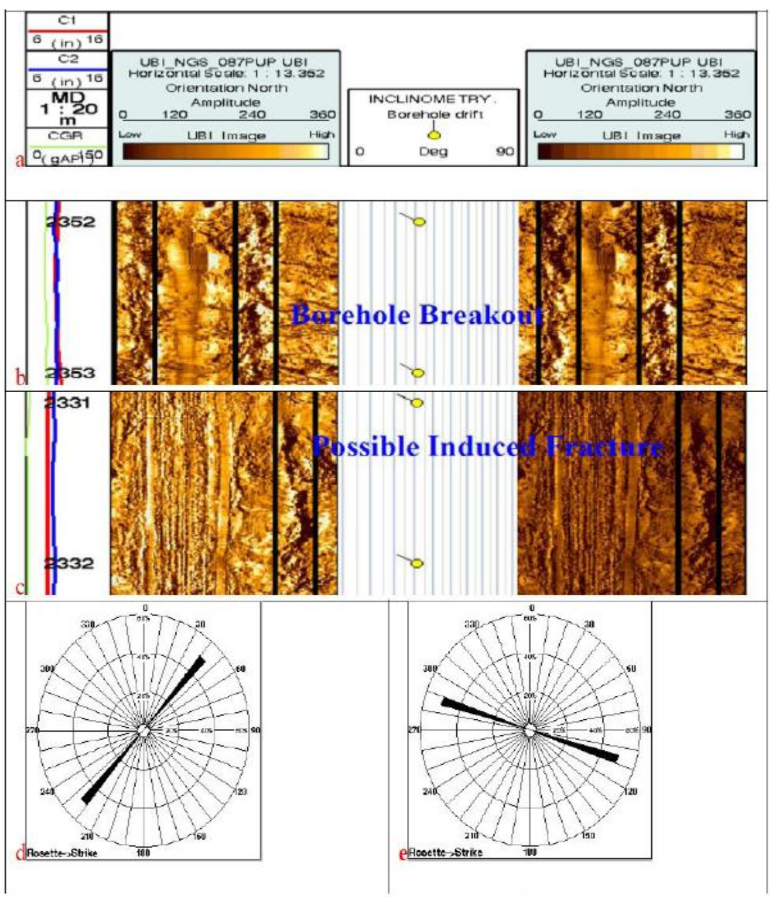

Figure 6 : a) UBI log header in well GS-B; b & c) UBI images show borehole breakouts striking almost NE-SW, which is parallel to σ_{hmin}, and the orientation of the drilling induced fractures that is WNW-ESE to be parallel to σ_{hmax} orientation; d) strike of σ_{hmin} in Schmidt projection& e) strike of σ_{hmax} in Schmidt projection

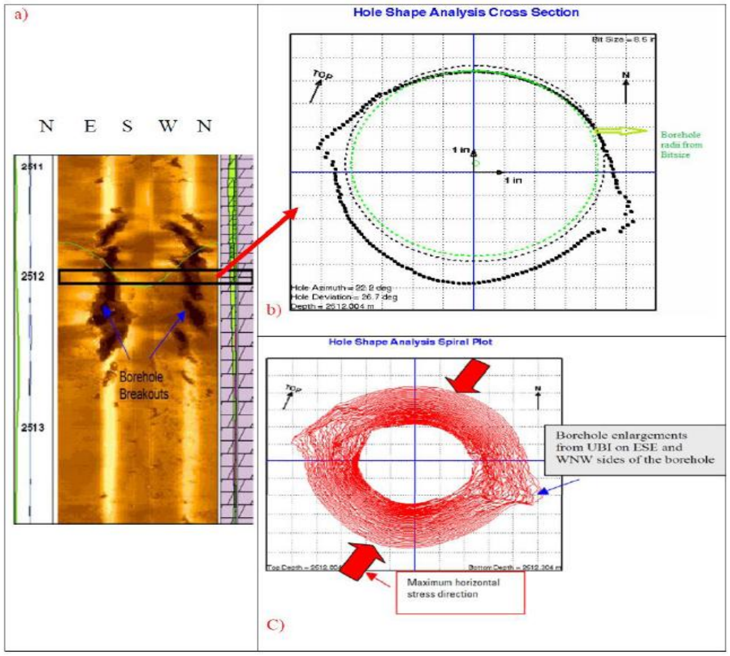

Figure 7 : a) In well GS-C, the UBI image of the borehole radius showing borehole enlargements (breakouts – black vertical stripes) around WNW and ESE sides of the borehole in the well GS-C; b) and c) The pipe's down-looking view of the borehole radii from the UBI

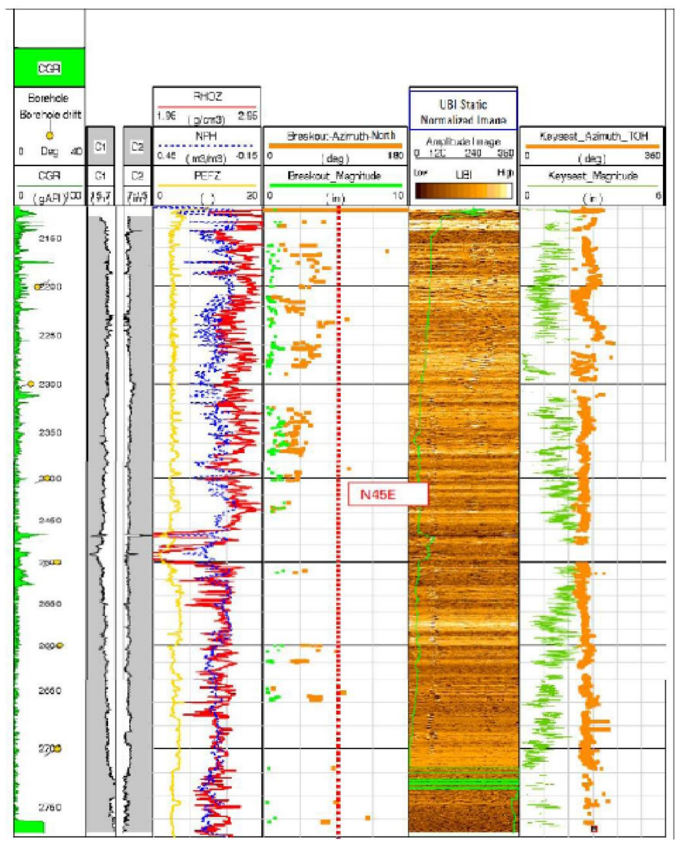

Figure 8 : In well GS-D, the composite plot of calipers and full set logs showing the borehole breakout and key seat azimuths and magnitudes which were derived from UBI images. The average breakout azimuth is N45E for the intervals with well deviation less than 20 degrees. Breakout azimuths in intervals with inclination higher than 20 degrees do not represent the exact orientation of breakouts. In such cases, breakout orientations need to be corrected

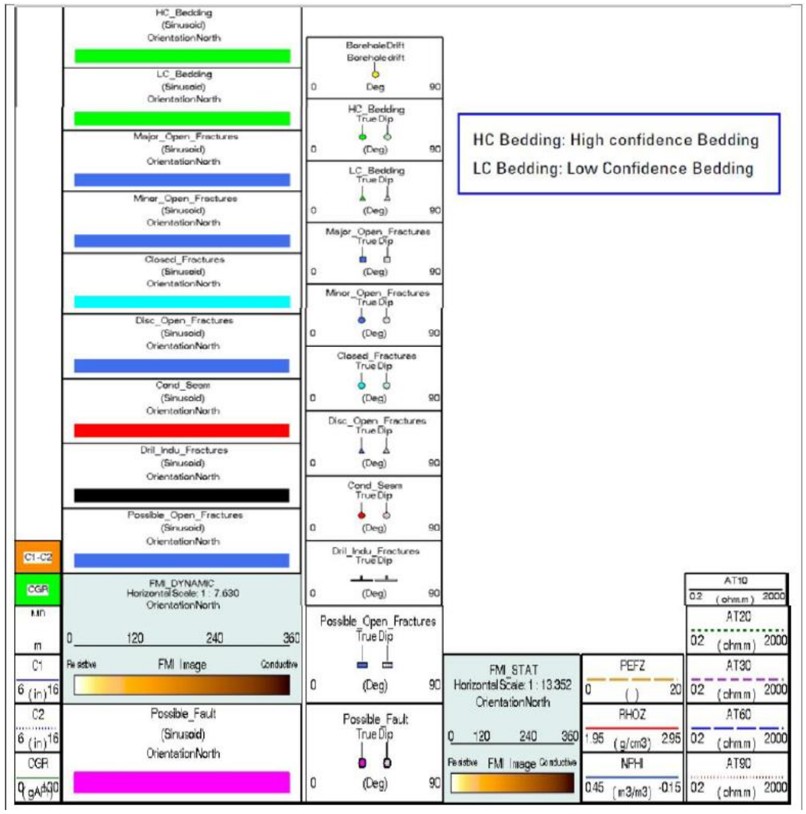

Figure 9 : Header details for Figures 10 and 11

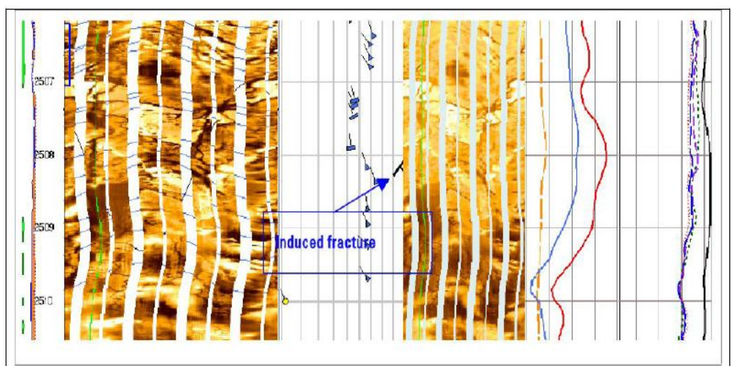

Figure 10 : In the well GS-E images shows the NE-SW trend for the drilling induced fractures in depth 2508m; header is given in Figure 9

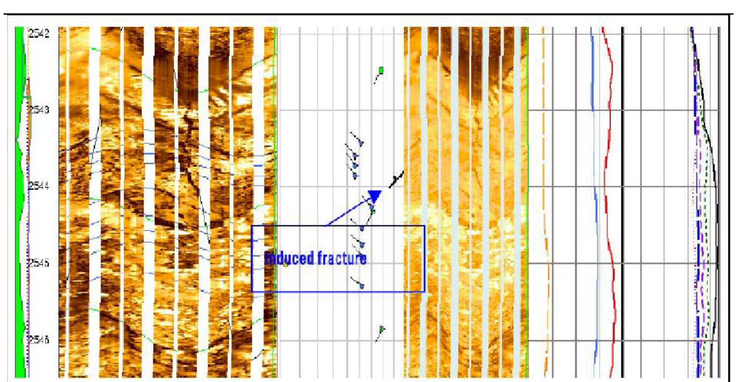

Figure 11 : In the well GS-E images shows the NE-SW trend for the drilling induced fractures in depth 2543m; header is given in Figure 9

wellbore. Borehole breakouts indicate the NE-SW orientation for σ_{hmin} and the NW-SE orientation for σ_{hmax}.

In-situ stress analysis for the well number GS-E

Two drilling induced fractures are observed in the upper section of the Asmari reservoir at 2508m and 2543m. The strike direction of these fractures is N45E-S45W, which roughly indicates that the orientation of σ_{hmax} around the well is NE-SW and the orientation of σ_{hmin} is NW-SE Figures 9 to 11.

In-situ stress analysis for the well number GS-F

No drill-induced fractures were observed in this well. However, a number of elliptical borehole breakouts, due to the shear failure of the borehole wall, are observed in the lower interval of the well at 2324m-2450m Figures 12 and 13. Only a few such features are identified in the remaining interval of the Asmari formation. The large majority of these elliptical breakouts have their longer axis orientation in the NW-SE direction, which indicates that the orientation of σ_{hmin} around the well is NW-SE and the orientation of σ_{hmax} is NE-SW.

In-situ stress analysis for the well number GS-G

The borehole breakouts were observed in this well. They are almost in whole interval and most of them exist inGurpi and Pabdeh formations. There are 5 induced fractures with a N15E-S15W strike that show the direction of maximum horizontal in-situ stress Figures 14 and 15. The large majority of these elliptical breakouts have their longer axis oriented in almost the WNW-ESE direction, which in-

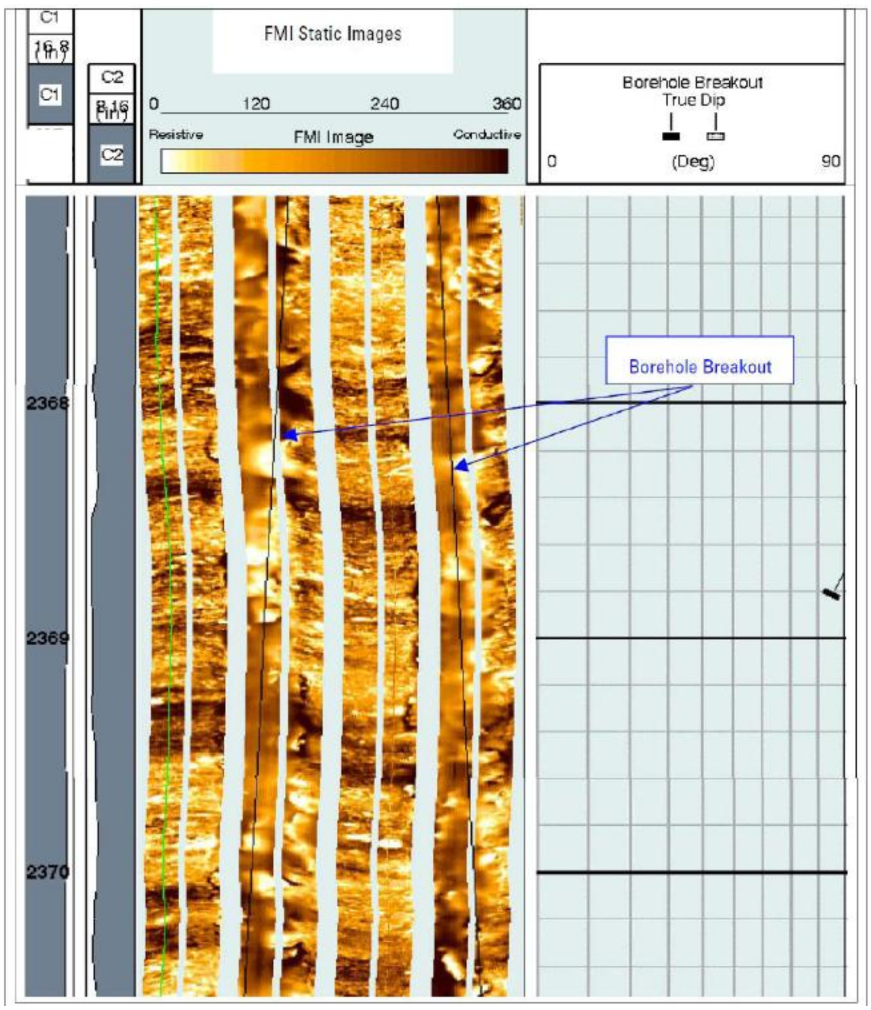

Figure 12 : In the well GS-F, the FMI images showing borehole breakouts on the images facing northwest (N60W to be more precise) and southeast (S60E to be more precise) sides of the borehole. Thus they indicate N60W-S60E trending for σhmin

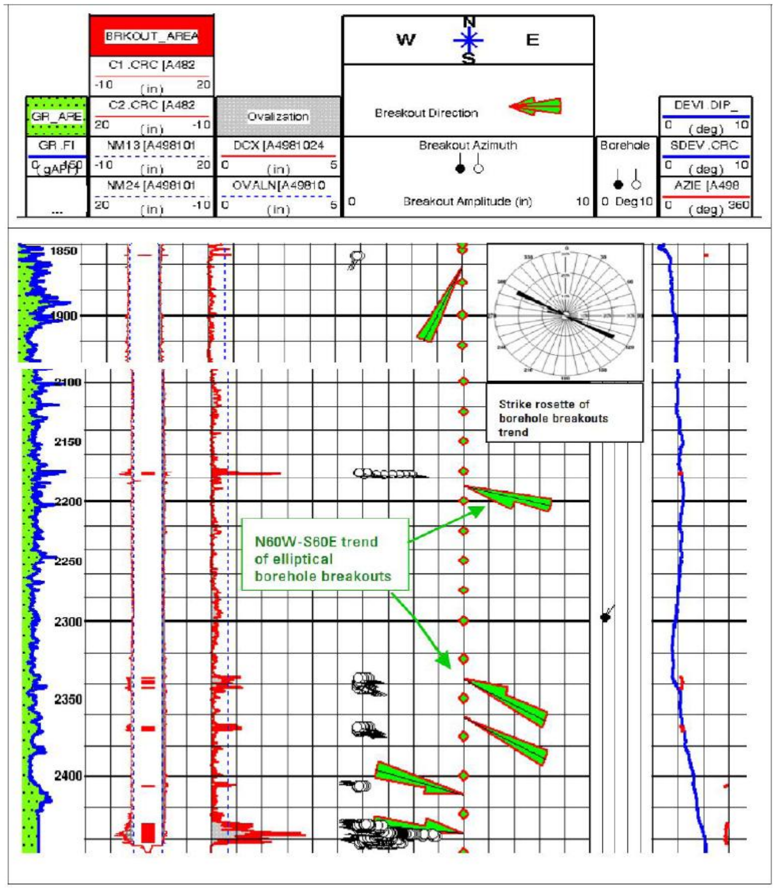

Figure 13 : In well GS-F, the logs showing dominantly N60W-S60E trending for borehole breakouts in Asmari formation. The breakouts were mostly observed in lower section. According to them the orientation of σhmin is N60W-S60E and the orientation of σhmax is N30E-S30W

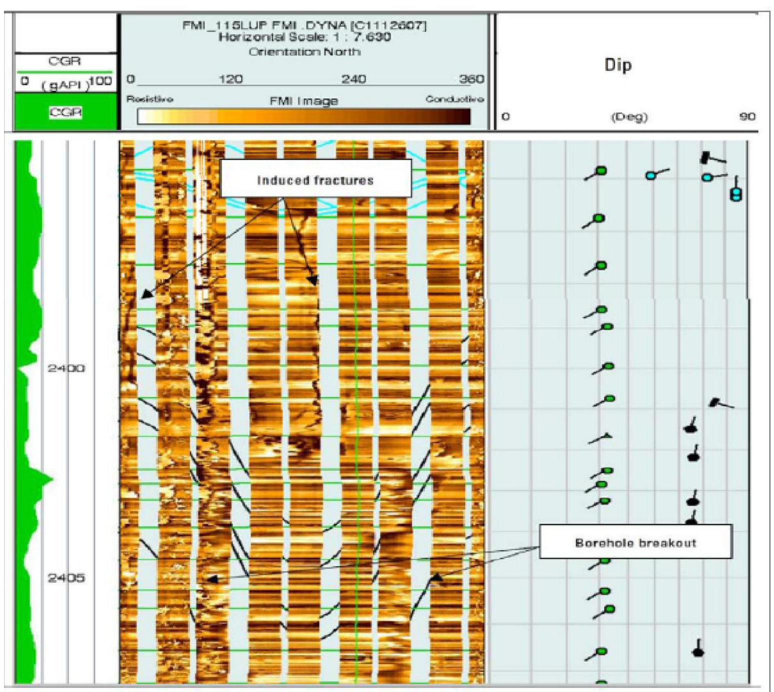

Figure 14 : In well GS-G, FMI images showing induced fractures in the upper part of the figure (2395m-2402m) and borehole breakouts in lower part (2402m-2407m). They have 90 degrees difference in the azimuth

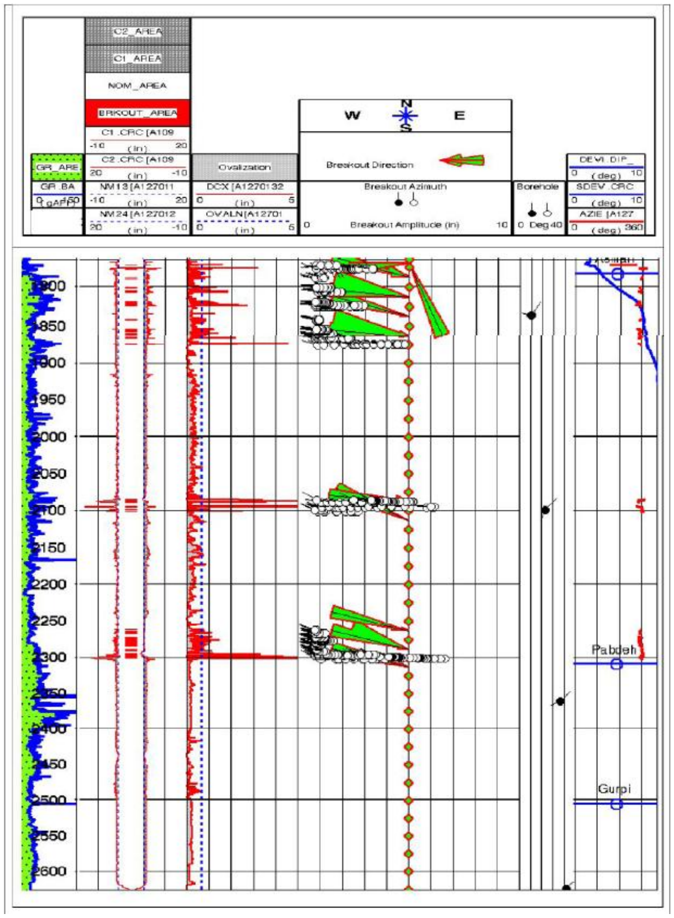

Figure 15 : In well GS-G, the logs showing the WNW-ESE trend for borehole breakouts in the Asmari formation. According to them the orientation of σ_{hmin} is WNW-ESE and the orientation of σ_{hmax} is NNE-SSW

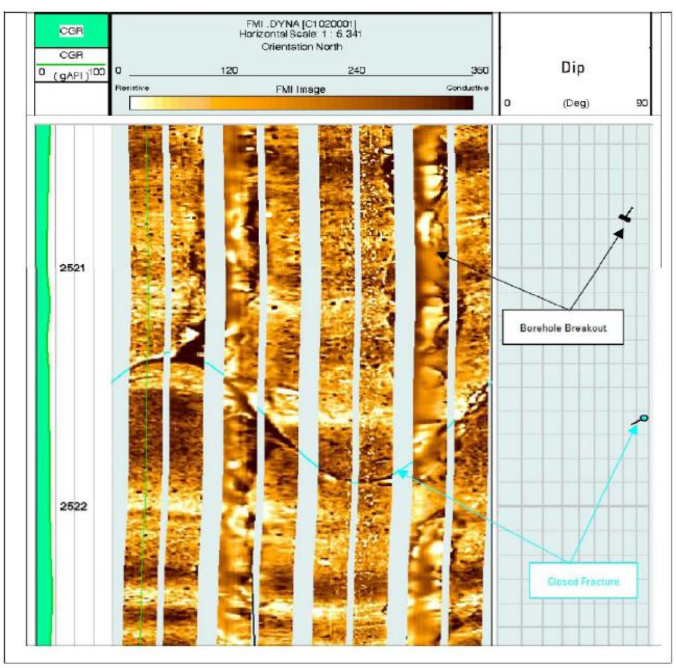

Figure 16 : In well GS-H, the FMI images showing borehole breakouts on the images facing northwest (N57W to be more precise) and southeast (S57E to be more precise) sides of the borehole. Thus they indicate N57W-S57E trending elliptical borehole breakouts that are aligned with σ_{hmin}

dicates the orientation of σ_{hmin} around the well, therefore the orientation of σ_{hmax} will be almost in the NNE-SSW.

In-situ stress analysis for the well number GS-H

The borehole breakouts were observed in the whole interval of the well and most of them exist in the Gurpi and Pabdeh formations Figures 16 and 17. The large majority of these elliptical breakouts have their longer axis orientation in almost N-E direction, which indicates that the orientation ofσ_{hmin} around this well is almost N-E and the orientation ofσ_{hmax} is N-S (N33E-S33W for σ_{hmax} and N57W-S57E for $\sigma_{hmin}$to be more precise).

In-situ stress analysis for the well number GS-I

The amplitude and radii images of the UBI do not show elliptical borehole breakouts in the Asmari formation, but a few drilling induced fractures were identified Figure 18. The orientation of the induced fractures is nearly N10E-S10W. It indicates the N10E-S10W orientation for σ_{hmax} and the N80W-S80E orientation for σ_{hmin}.

In-situ stress analysis for the well number GS-J

The FMI images show induced fracture on the images facing northeast and southwest sides of the borehole. Thus they indicate NNE-SSW trending elliptical induced fractures that are aligned with σ_{hmax} Figure 19. The direction of σ_{hmin} is NNW-SSE.

DISCUSSION

In Gachsaran field, Wells number GS-A, GS-C, GS-E, GS-F, GS-G, GS-H and GS-I almost follow the NE-SW direction for maximum horizontal in-situ

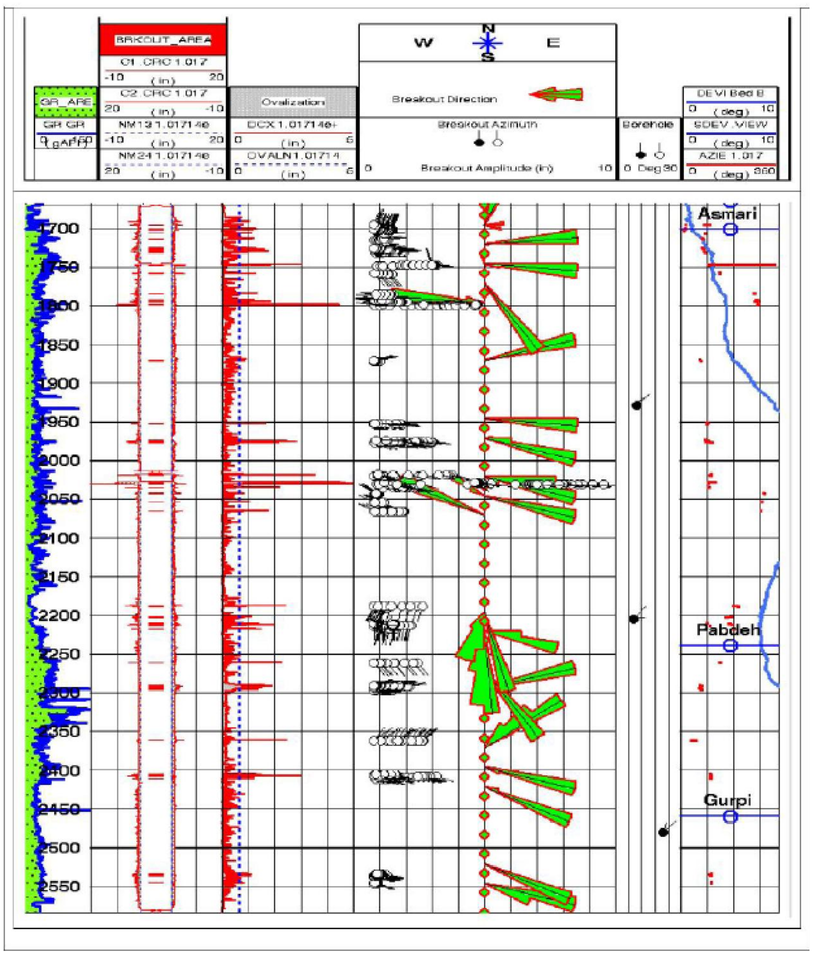

Figure 17 : In well GS-H, the logs showing E-W trend for the borehole breakouts in the Asmari formation and the NW-SE trend in thePabdeh and Gurpi formations. The breakouts were mostly observed in thePabdeh formation. The borehole trend in Pabdeh formation is slightly different from theAsmari formation. According to them the overall orientation of σ_{hmin} is N57W-S57E and the orientation of σ_{hmax} is N33E-S33W

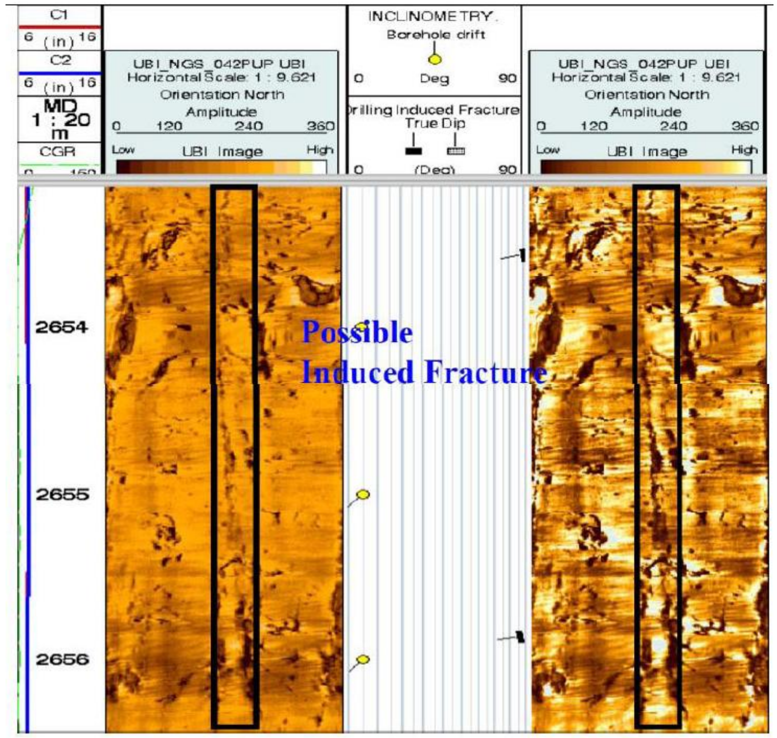

Figure 18 : The UBI image showing drilling induced fractures in the wellGS-I

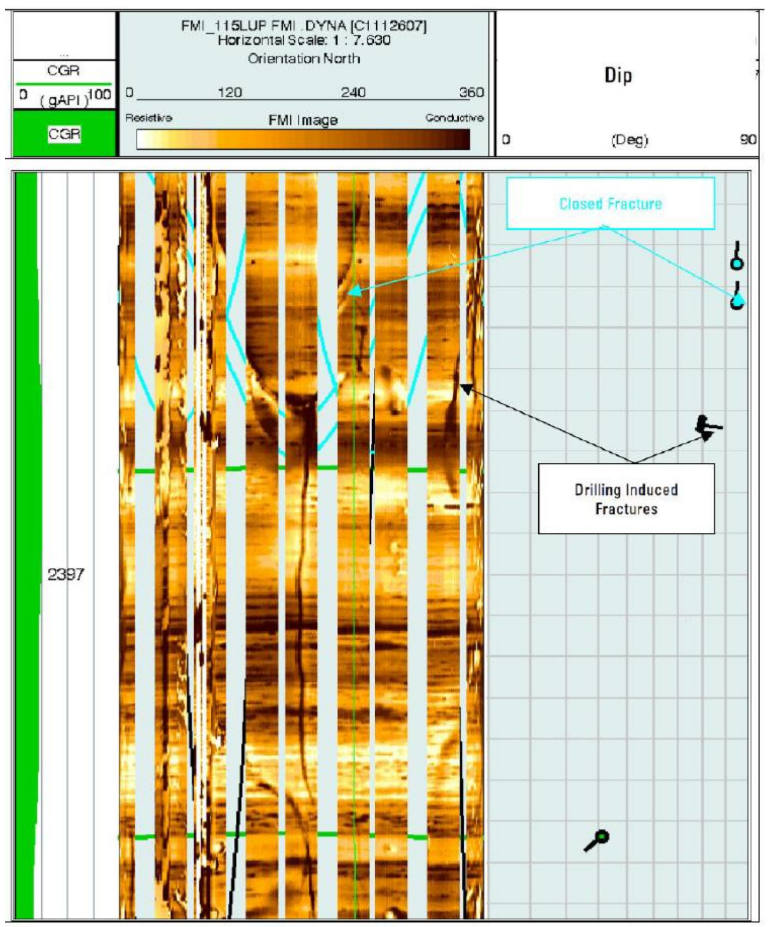

Figure 19 : The FMI images in well GS-J showing induced fractures

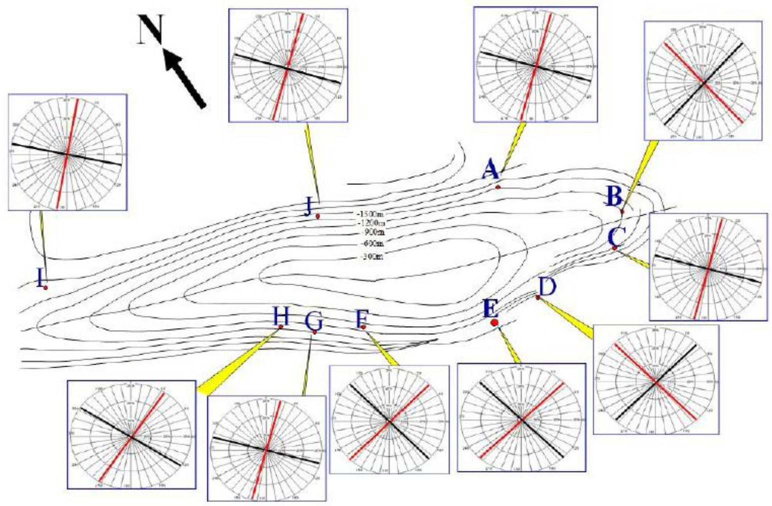

Figure 20 : σ_{hmin} direction (black color) and σ_{hmax} direction (red color) for all the studied wells in Gachsaran field

stress direction, and NW-SE for minimum horizontal in-situ stress direction. It shows that for this field, the direction of maximum horizontal in-situ stress is NE-SW, and the direction of minimum horizontal in-situ stress is NW-SE.

The In-situ stresses direction for the wells number GS-B and GS-D are quite different from the other wells, and the reason might be the effect of fault, fold and diapirism near these wells (Figure 20). For these two wells, further structural analysis and fault interpretation are needed to find out the exact reason for this difference.

CONCLUSIONS

In this job, we found out the in-situ stresses direction ofGachsaran field. NE-SW for maximum horizontal in-situ stress and NW-SE for minimum horizontal in-situ stress. By having the result of this job, any hydraulic fracturing operation, EOR operations, drilling operations and the other operations for this field can be planed more accurate.

REFERENCES

[1] F.Khoshbakht, H.Memarianb, M.Mohammadniaa; Comparison of Asmari, Pabdeh and Gurpi formation's fractures, derived from image log, Journal of Petroleum Science and Engineering, doi: 10.1016/ j.petrol.2009.02.011, **67**, 65-74 **(2009)**.

[2] Google Maps, Gachsaran; Kohgiluyeh Va Boyer Ahmad, Iran **(2014)**.

[3] Z.Movahed; Enhanced Reservoir Description in Carbonate and Clastic Reservoirs, Paper presented at the SPE Asia Pacific oil & Gas Conference and Exhibition, Jakarta, Indonesia, 30 October-1 November **(2007)**.

[4] Weiren Lina, En-Chao Yehb, Jih-Hao Hungc, Bezalel Haimsond, Tetsuro Hironoe; Localized rotation of principal stress around faults and fractures determined from borehole breakouts in hole B of the Taiwan Chelungpu-fault Drilling Project (TCDP), Tectonophysics, doi:10.1016/ j.tecto.2009.06.020, **482**, 82-91 **(2010)**.

[5] Xin Nie, Changchun Zou, Li Pan, Zhaohui Huang, Dongming Liu; Fracture analysis and determination of in-situ stress direction from resistivity and acoustic image logs and core data in the Wenchuan Earthquake Fault Scientific Drilling Borehole-2 (50–1370 m), Tectonophysics, doi: 10.1016/ j.tecto.2013.03.005, **593**, 161–171 **(2013)**.

[6] Z.Movahed et al.; Formation evaluation in Dezful embayment of Iran using oil-based-mudimaging techniques, J.Petrol.Sci.Eng., doi: 10.1016/ j.petrol.2014.05.019i **(2014)**.

[7] B.Aadnoy, R.Looyeh, Petroleum Rock Mechanics, Drilling operations and Well Design, GULF Publishing Company, Houston, Texas, United States, ISBN: 978-0-12-385546-6., Chapter 8 - In-Situ Stress: 107-129, doi: 10.1016/B978-0-12-385546-6.00008-5, Chapter 9 - Rock Strength and Rock Failure: 131-149, doi: 10.1016/B978-0-12-385546-6.00009-7, Chapter 10 - Stresses Around a Wellbore: 151-172, doi: 10.1016/B978-0-12-385546-6.00010-3 **(2011)**.