Journal of Petroleum
Science and Technology

The Effect of Fault Plane on the Horizontal In Situ Stresses Orientation: a Case Study in one of Iranian Oilfield

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ABSTRACT

Knowledge of the orientation of horizontal in situ stresses is important to some areas of oil and gas field development plans. Borehole breakouts observed in image logs and drilling-induced fractures are the main parameters for the determination of the stresses' directions in situ.

In this work, the orientations of borehole breakouts were investigated as a function of depth in oil wells A and B in Lali oilfield, in the Southwest of Iran. Borehole breakouts were detected from FMI logs. By the statistical analysis of the borehole breakouts' orientation in the foregoing two wells, it was found that, while a mean orientation of minimum horizontal stress in well A is NE-SW, the azimuth of breakout in well B is different with a mean azimuth of 312°±10°. The result reveals that the orientation must be different in these two wells due to some geological abnormality. Therefore, accurate and reliable geomechanical analyses are crucial steps toward minimizing the costs of drilling and completion programs and mitigating borehole instability problems.

Keywords: In Situ Stresses, Borehole Breakout, Drilling-induced Fractures, Lali Oilfield

INTRODUCTION

Borehole breakouts and drilling-induced fractures (DIF's) are important indicators of horizontal stress orientations [1]. Knowledge of the orientation of horizontal in situ stresses derived from the analysis of borehole breakouts is important for planning hydrocarbon exploration strategies; developing production strategies; engineering reservoirs, drilling, and wellbore mechanics; and studying crustal stress and rock mechanics [1].

Borehole breakouts are stress-induced enlargements of the wellbore cross-section [2].

When a borehole is drilled, the material removed from the subsurface is no longer supporting the surrounding rock. As a result, the stresses become concentrated across the surrounding rock (including the wellbore wall). Borehole breakouts occur when the stresses around the borehole exceed the compressive strength of the borehole wall [3]. The enlargement of the wellbore is caused by the development of intersecting conjugate shear planes that cause spalling of the fragments of the formation being drilled. Around a vertical borehole, stress concentration is generally greatest in the direction of the minimum horizontal stress. Hence the long axes of borehole breakouts are oriented approximately perpendicular to the maximum horizontal stress orientation [4].

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Articale history
Received: February 23, 2015
Received in revised form: December 23, 2015
Accepted: January 31, 2016
Available online: February 20, 2017

Journal of Petroleum Science and Technology **2017**, 7(1), 35-41

Borehole Failures Analysis by Image Logs

Borehole breakouts can be determined by using image logs [4, 5]. There are currently a wide variety of imaging tools that fall into two general categories of acoustic and resistivity tools. In this study, formation micro imager (FMI) logs were used to determine borehole breakouts and fault planes. FMI is a resistivity imaging tool which provides an image of the wellbore wall based on resistivity contrasts [6,7].

Figure 1a illustrates borehole breakouts and tensile induced fractures as dark bounds and dark lines respectively [8], while Figure 1b is showing the transverse induced fracture in one of the Iranian oil wells. As it can be seen in Figure 1b, discriminating between transverse induced fractures and natural fractures or bedding is so difficult that an accurate interpretation would run into difficulty without the knowledge of a comprehensive geomechanics model. Indicating such high conductivity fractures, Barton and Zoback have presented a method for distinguishing induced fractures from natural fractures by using reservoir geomechanical models and fitting a flexible sinusoid to the pair of fractures [9].

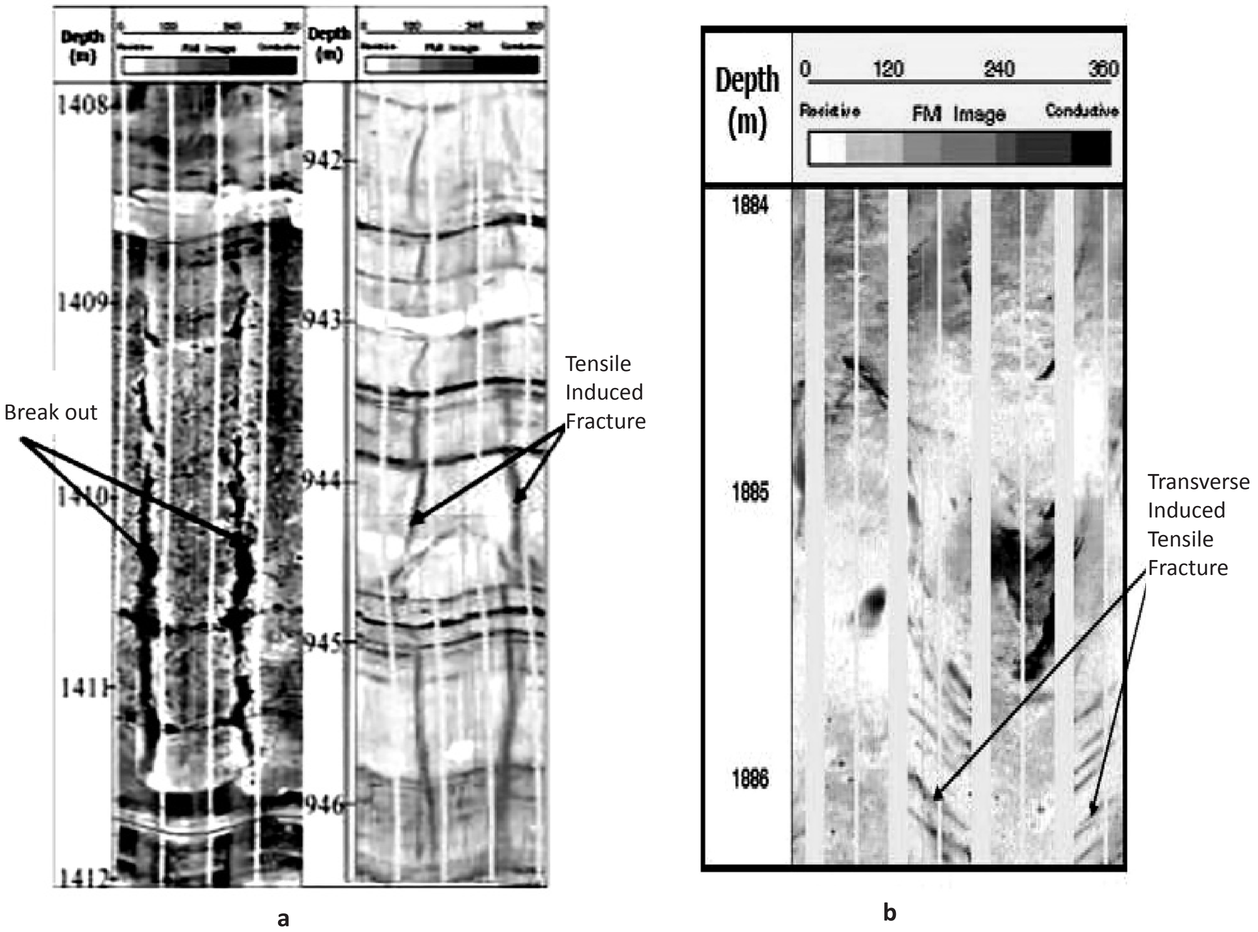

Figure 1: (a) An FMI log example of borehole breakout and tensile induced fracture [8], and (b) an FMI log example of transverse induced tensile fracture in one of Iranian oil wells.

As tensile induced fractures are controlled by the orientation of tectonics stresses and are not formed continuously around the borehole wall, they propagate only in tensile regions of borehole wall where the hoop stress exceeds the rock Itensile strength [9]. The best approach to distinguish induced fractures from natural fractures is comparing the results of image logs with the fractures observed on the core samples.

Detection and determination of faults are also one of the most important applications of image logs in the field of structural geology. Fault is a displaced planar fracture or discontinuity in a volume of rock. If the displacement across the plane of a fault is lower than the wellbore diameter, we can then observe it on the image log directly. However, if the displacement across the fault plane is further than the wellbore diameter, the indirect observations such as sudden changes in the dip and azimuth of layering (structural dip change), truncated bedding, the concentration of fractures in the area of sheared zones, and the development of borehole breakouts can be employed. Figure 2 shows the effect of normal fault on the FMI log in one of Iranian oil fields.

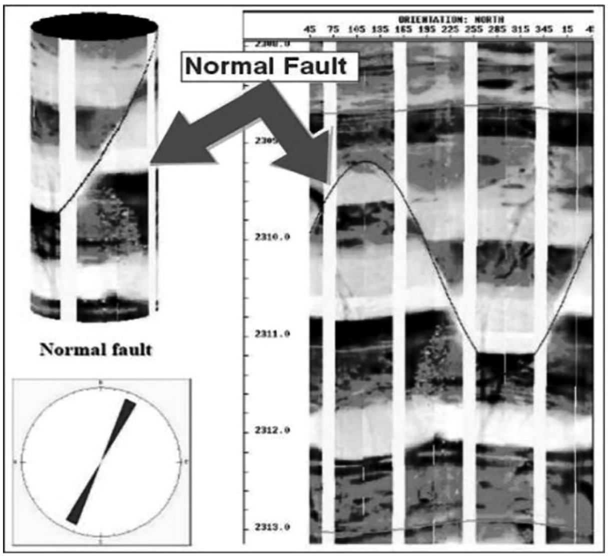

Figure 2: The effect of normal fault on the FMI log in one of Iranian oil wells.

In this paper, borehole breakouts detected by FMI log in wells A and B are investigated. Although wells A and B are not relatively far from each other, the orientation of borehole breakouts or horizontal in situ stresses is significantly different. Here, we will discuss the reasons for this event.

Stress Orientation in Lali Oil Field

Figure 3 illustrates the maximum horizontal stress orientation map of Iran [10]. Each symbol indicates the type of stress measurement and each color shows the corresponding stress regime. As Figure 3 shows, the only method reported for stress measurement in Iran is the focal mechanism. In this figure, red color indicates normal faulting (NF), green color indicates strike-slip (SS), blue color indicates thrust faulting (TF), and “U” is an unknown tectonic regime [10]; most of them are thrust faulting regimes. Since a significant number of Iranian oil and gas reservoirs are located in the south and southwest of Iran, in which the state of stress is the mainly thrust faulting regime, the borehole instability problems,

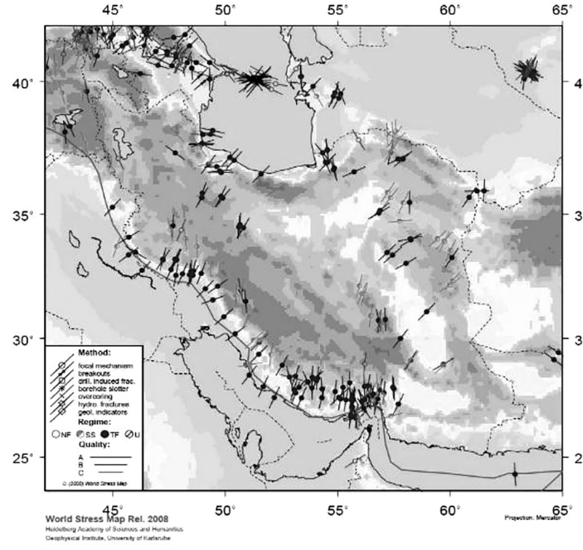

Figure 3: Map of maximum horizontal stress orientations in Iran for all the data with different stress measurements on the regional topographic base [10].

such as, stuck pipe, lost circulation, sand production, and casing collapse frequently occur at the borehole wall while drilling and later during production. Therefore, accurate and reliable geomechanical analyses are crucial steps toward minimizing costs of drilling and completion programs and mitigating the borehole instability problems.

The anticline of the Lali Oilfield is located in the southwest of Iran. It has an asymmetric structure, in which the dip of southern flank is more than the northern one. According to underground contour (UGC) map, the maximum dip of southern flank is 35°. Also, the axis of this anticline in the West tends to North and in the East, tends to South. The Asmari reservoir of this field, for the first time, was explored in 1938 and drilled to the depth of 1768 m (383 m in Asmari formation). So far, 27 wells have been drilled in Lali oilfield. Only two wells A and B have available data. Unlike well A, which was drilled into the Asmari and the Pabdeh formations at the depth ranging from 2072 to 2439 m, well B was penetrated only through the Asmari formation between the depths of 1544 to 2066 m. The dominant lithology of the Asmari formation in the Lali Oilfield is limestone. In some areas, it is composed of dolomite limestone and lime shale with seams of anhydrate [11].

By interpreting and observing the image logs in the vertical interval of wells A and B, borehole breakouts without any tensile induced fracture were detected in both wells. Figure 4 shows the borehole breakout recorded by FMI log in well A (Figure 4a) and well B (Figure 4b).

Breakouts are seen as the vertical stripes of dark colors in FMI logs. As it can be seen from Figure 4, the orientations of borehole breakouts in well A are almost NE–SW, whereas in well B, it appears to be along NW–SE orientation.

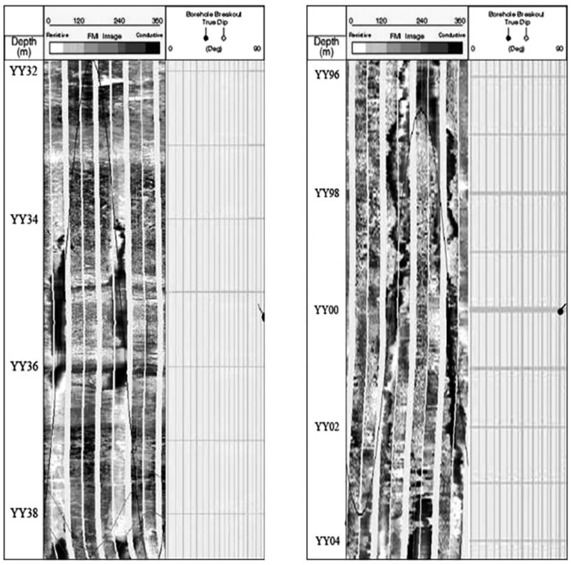

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Figure 4: (a) FMI log of 6 m in well A and (b) 8 m in well B; the dark color in image logs indicates the location of low reflected amplitude (low resistivity) caused by breakout zone.

Figures 5a and 6a show the depth of occurrence and the orientations of borehole breakouts, defined by gray points, in wells A and B respectively. As illustrated in these figures, the orientations of borehole breakouts remain the same with depth in both wells.Figures 5b and 6b illustrate the frequency of breakout dip angle and orientation in wells A and B respectively. Figure 7 also shows the rose diagram of induced fracture in well B. As it can be seen from Figure 7, the induced fractures are vertical in well B (a vertical well). In addition, since a mean dip direction is derived near vertical (90˚) and borehole breakouts offset by 180˚ at borehole wall (Figure 5 and Figure 6), the plane of principal stresses must be horizontal in both wells. It is found by rose diagram that a mean azimuth of borehole breakout in well A is 37˚±15˚(Figure 5b), and it is, however, 312˚±10˚ in well B (Figure 6b).

According to Figure 3, which shows the orientation of horizontal in situ stresses in Iran, it would be expected that the orientations of borehole breakouts in both wells are similar with a mean azimuth of about NE-SW. This principal is observed in well A, but as Figures 5 and 6 show that well B is a special case, and there is no correspondence between the horizontal in situ stresses direction in this well and the world stress map of Iran.

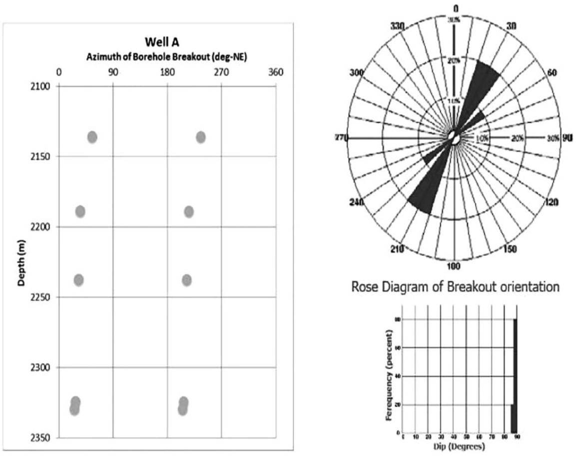

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Figure 5: (a) Depth versus the borehole breakout orientation (gray points) at a depth of 250 m of well A; (b) (upper) the rose diagram of 5 data record and (lower) the frequency of dip direction of breakout.

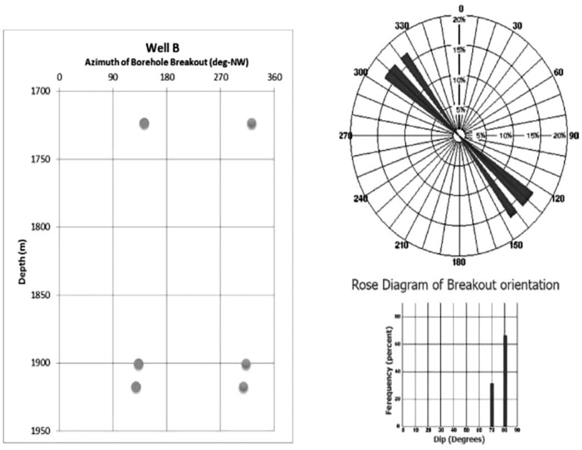

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Figure 6: (a) Depth versus the borehole breakout orientation (gray points) at a depth of 250 m of well B; (b) (upper) the rose diagram of 3 data record and (lower) the frequency of dip direction of breakout.

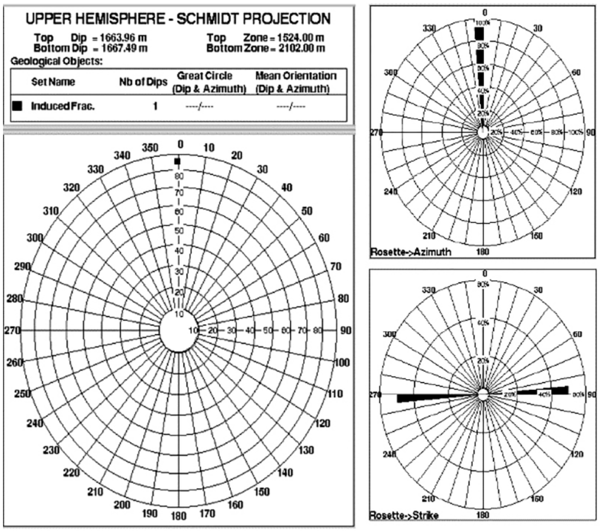

Figure 7: Rose diagram of induced fracture in well B.

Image log analyses suggest that significant changes of the borehole breakout orientation with a depth in accordance with the borehole axis or between neighboring wells are explained by the influence of geological heterogeneities; such as, faults, folds, and salt diaper; however, they are often due to slip on fault, and the variations may be seen while approaching a fault [12]. In this investigation, the result reveals that the orientations must be different in these two wells due to some geological abnormality.

The Effect of Faults on Borehole Breakout Orientations

Many faults have been detected by the interpretation of FMI logs in well B. Figure 8 shows the major fault plane in well B, since the distinct changes have been observed in layering structure in the wellbore wall from top to the depth of 1816 m. As it can be seen from Figure 8, the upper layers have a dip in the direction to S35°W, while gradually to the bottom, the dip is increasing and at depth of 1816 m, the dip direction has reversed suddenly to NE.

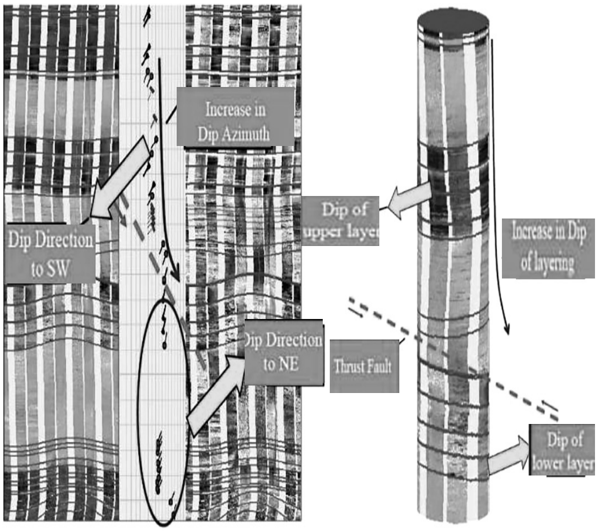

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Figure 8: (a) The effect of the major fault plane at a depth of 1816 m in well B on the FMI log and (b) 3D view of the FMI log.

So, the depth of 1816 m could be considered as the location of the major fault plane. To detect a fault, indicators are required. All the factors such as conditions governing the status of drilling, partial knowledge of regional geological condition, seismic profiles, and even pressure data inside the well could help to recognize a fault in a region or on the well scale. In this case, the downward movement of the cap rock and the Asmari formation compared to the drilling forecast program was another reason for detecting this event.

Figure 9a shows the depth of occurrence and orientations of faults, defined by gray points in well B respectively. As shown in this figure, the orientation of the fault is constant with depth. Figure 9b illustrates the frequency of the fault orientation in well B. It is found by a rose diagram that a mean azimuth of the fault in well B is 300°±10°. By the determination of faults strike in well B, it is clear that the fault strike is different from the one in well A. Therefore, the change in the orientation of borehole breakouts or minimum horizontal in situ stresses in well B is justifiable.

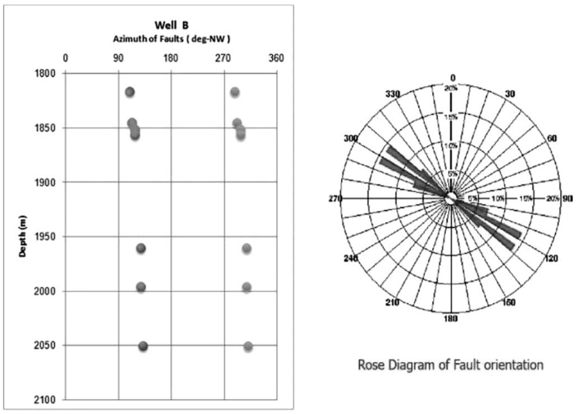

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Figure 9: (a) Depth versus the fault orientation (gray points) at a depth of 300 m of well B; (b) the rose diagram of 7 data illustrates that a mean azimuth of faults is 300˚(s.d.=10˚).

Applications

Where in situ stresses are disturbed around large scale fractures, such as, faults the direction of principal stresses can deviate from the regional trend to a completely new direction [13]. This can have a great impact on engineering design and planning. For well B, the results indicate this point. Knowledge of principal in situ stresses orientation is crucial in some areas of petroleum industry. In this case, drilling reports have shown that lost circulation is negligible in well A, but, for well B, it is about 40 bbl/hr from the depths of 1544 to 2066 m. This event in well B is due to the lack of the knowledge of geomkechanical modeling (in situ stresses orientation, stresses magnitude, rock mechanic properties, etc.), which causes borehole instability problems during the drilling operation. By knowing the horizontal in situ stress orientation in a region, engineers can determine the optimum deviation and azimuth for drilling nearby planned wells in a way to improve borehole stability.

CONCLUSIONS

In this work, the orientation of borehole breakouts and induced fractures were investigated as a function of depth in oil wells A and B in the Lali oilfield in the southwest of Iran. It was concluded that drilling induced fractures are vertical in the Lali oilfield; therefore, the plane of principal stresses are vertical-horizontal. It was also concluded that while a mean orientation of minimum horizontal stress in well A is NE-SW, the azimuth of breakout in well B is different with a mean azimuth of 312°±10°. The results reveal that the orientation must be different in these two wells due to some geological abnormality. This study has indicated that a drilled well becomes closer to the plane of existing faults in the field, and this causes stress perturbation. This has also caused the direction of the minimum horizontal stress to be changed significantly, about 90°, in accordance with another nearby well.

ACKNOWLEDGEMENTS

Authors thank National Iranian South Oilfield Company's staffs and advocates for their help and support during this work and providing sufficient datasets used herein.

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