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Analysis of In-Situ Stress and Well Trajectory in Carbonate and Sandstone Reservoirs. A Case Study of Mishrif and Zubair Formations in the West Qurna Oilfield, Southern Iraq

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Abstract

Reservoir Geomechanics plays a crucial role in maximizing the efficiency of the drilling process, guaranteeing accurate placement of horizontal wells, and accomplishing effective well completion. Accurately determining the levels of pore pressure and the vertical, minimum, and maximum horizontal stresses is a crucial component of thorough geomechanical modeling. Mishrif carbonate reservoir in the Middle Cretaceous and Zubair sandstone reservoir in the Lower Cretaceous are the essential reservoirs in the West Qurna oilfield, southern Iraq. This study aims to analyse the best Well trajectory conditions in the carbonate and sandstone reservoirs using many correlations for thirteen wells (that were drilled from 2014 to 2016) in the West Qurna/1 field.

The findings indicate that the geomechanical problems in Mishrif wells are less severe compared to Zubair wells concerning optimizing pore pressure and the presence of geo-pressurized shale sequence.

In addition, Mishrif wells in the eastern flank of the oilfield are less prone to drilling mud loss problems than the western flank. All the wells drilled towards maximum horizontal stress showed minimal wellbore stability problems in which the best average maximum horizontal stress direction is 55 +/- 20 and 235 +/-20 deg. Mishrif wells are less sensitive to azimuth and deviation than Zubair wells. On the other hand, Zubair wells are more sensitive to inclination. The maximum horizontal stress direction is recommendable to reduce Well complexity and challenging drilling environment. To establish the drilling window during drilling operations in the West Qurna 1 field, it is necessary to have a formation prediction that takes into account lithology and anticipated wellbore stability pressures.

Keywords: West Qurna; Carbonate and Sandstone; Mishrif and Zubair; In-situ stress; Well trajectory.

تحليل الإجهاد في الموقع ومسار البئر في المكامن الكربونية والرملية. دراسة حالة لتكويني المشرف والزبير في حقل غرب القرنة/1 النفطي، جنوب العراق

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الخلاصة

تعد الميكانيكا الجيولوجية للخزان أمرًا ضروريًا لتحسين عملية الحفر، وضمان وضع البئر الأفقي الناجح، وتحقيق استكمال البئر بكفاءة. يعد التقييم الدقيق لأحجام ضغط المسام والضغوط الأفقية الرأسية والحد الأدنى والحد الأقصى جانبًا مهمًا للنمذجة الجيوميكانيكية الشاملة. يعد خزان كربونات المشرف في العصر الطباشيري

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الأوسط ومكمن الحجر الرملي الزبير في العصر الطباشيري السفلي من الاحتياطيات الأساسية في حقل غرب القرنة النفطي جنوب العراق. تهدف هذه الدراسة إلى تحليل أفضل ظروف مسار الآبار في مكامن الكربونات والحجر الرملي باستخدام العديد من الارتباطات لثلاثة عشر بئراً (تم حفرها من عام 2014 إلى عام 2016) في حقل غرب القرنة/1 النفطي.

أظهرت النتائج أن المشاكل الجيوميكانيكية لآبار مشرف أقل خطورة من آبار الزبير من حيث تحسين ضغط المسام وتسلسل الصخر الزيتي المضغوط جغرافيا. بالإضافة إلى ذلك، فإن آبار مشرف الواقعة في الجانب الشرقي من الحقل النفطي أقل عرضة لمشاكل فقدان طين الحفر من الجانب الغربي. أظهرت جميع الآبار التي تم حفرها نحو الحد الأقصى من الإجهاد الأفقي مشاكل في استقرار البئر حيث يكون أفضل متوسط لاتجاه الضغط الأفقي الأقصى هو 55 +/− 20 و 235 +/− 20 درجة.

تعتبر آبار مشرف أقل حساسية للسمت والانحراف من آبار الزبير. ومن ناحية أخرى فإن آبار الزبير أكثر حساسية للميل. يوصى باستخدام الحد الأقصى لاتجاه الضغط الأفقي لتقليل تعقيد البئر وبيئة الحفر الصعبة. مطلوب تشخيص التكوين المعزز بالليثولوجية وضغوط استقرار حفرة البئر المتوقعة لتحديد نافذة الحفر أثناء عمليات الحفر في حقل غرب القرنة 1.

1. Introduction

The internal tension, which exists in the earth's crust, in another meaning, is the in-situ stress, which is the stress that results from the load in the first face, and the tectonic stress is the other face [1.2]. The origin of load stress, like the superimposing rock cluster, is the overburden stress and can be dealt with the mass weight [3].

Tectonic stresses have resulted from complex techniques that make the precise description more difficult [4]. The accurate measurements of in-situ stress are necessary to assess well productivity, which directly affects the azimuth and direction of the permeable cracks [5]. The stability of the borehole is influenced by the in-situ stresses, pore pressure, and the integrity of the rock. The primary formation and drilling mud pressure will exist in the drilling processes [6]. Pore pressure distribution occurs around the wellbore in the drilling process, so the stress distribution and drilling conditions could change [7]. Many studies discussed the optimum well trajectory from the viewpoint of the drilling and production issues, which are influenced by indifferent in-situ stress regimes. A noticeable effect on the wellbore inclination and azimuth has been identified during the potential sanding onset process [8], considering that production problems are desired in optimum Well trajectory planning of the new wells to decrease sand output prohibitions [9].

Many factors (exactly nine) affect stress in rocks, and only six are independent [10]. The stresses in the rock mass represent three principal stresses: The vertical stress (σv), the maximum horizontal stress (σH), and the minimum horizontal stress (σh), and their orientations [4] (Figure-1). To mitigate the negative effects of formation damage on pressure loss during well drilling, it is necessary to employ techniques that reduce higher pressures. This will result in increased production rates and improved recovery factor (RF) [11]. Nevertheless, the ejection of sand from the wellbore becomes apparent when the rock's integrity is exceeded during the execution of the well [12].

Adjustment of the wellbore stability for the wells under design according to the Well pressure will be essential to secure acceptable stress concentrations generated around the well. That maintains wellbore stability.

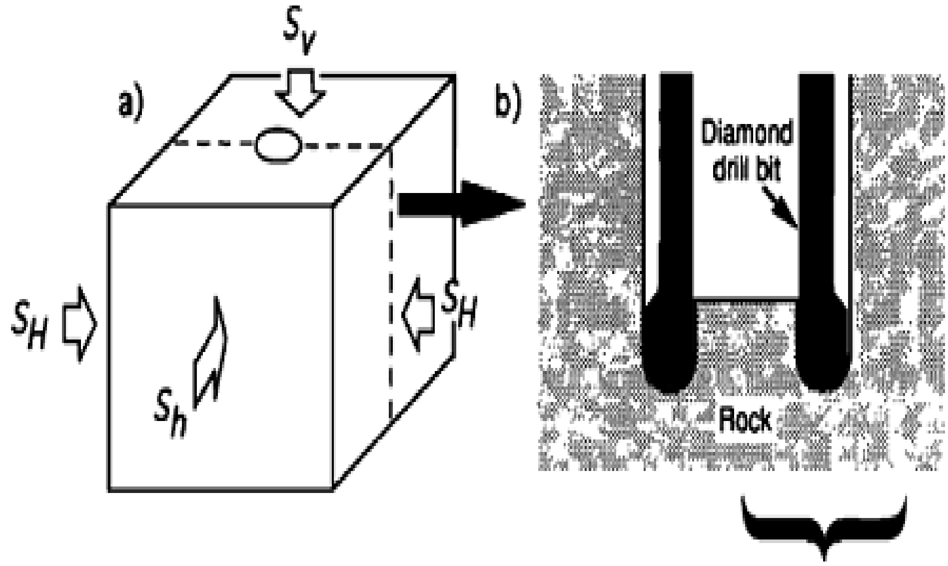

Figure 1: A Stress condition of the modelling, B coring with a diamond drill bit [13]

1.1 The effect of pore pressure on borehole stability

The effect of rising or reducing pore pressure on the inclination and orientation of borehole breakout and tensile will prompt the fractures in any borehole to be apparent according to the frictional strength of the earth and reduction in the stress anisotropy at overpressure depth [14].

The laboratory Geomechanics tests and field in-situ stress measurements demand an essential on top of the cost and additional time, while the results obtained may only be for limited formations and only a few wells in an oilfield [15]. Any estimation of the characterizations in the laboratory does not match the actual circumstances. Therefore, developing new techniques that identify geomechanical characterizations or in-situ stress in an economical and rapid procedure requires many attempts. For instance, empirical correlations between rock mechanical characteristics as measured by sonic and density records or rock physical characteristics have been confirmed [16, 17]. The calibrated petrophysical logs are a significant tool for estimating the mechanical characteristics and in-situ stress and constructing the geomechanical modeling [18]. Based on the formation pressure failure of the borehole to the random trajectory, a procedure to estimate the orientation and magnitudes of horizontal in-situ stresses has been modified [19, 20]. By numeral simulation, the effect of the tensile and shear tendencies of rock on the disfigurement of the borehole has been examined [21]. Artificial intelligence methods and different algorithms are essential to chart the correlation between in-situ stress and the displacements of a borehole wall [22]. Further research employs the Finite Element Method (FEM) to calculate the diameter and depth of fractures at the borehole in order to ascertain in-situ stress [23].

2. Geological Setting

The West Qurna oilfield is one of the giant Oilfields in southern Iraq, located about 70 Km Northwest of Basra city and 14 km West of Qurna city (Figure 2) [24].

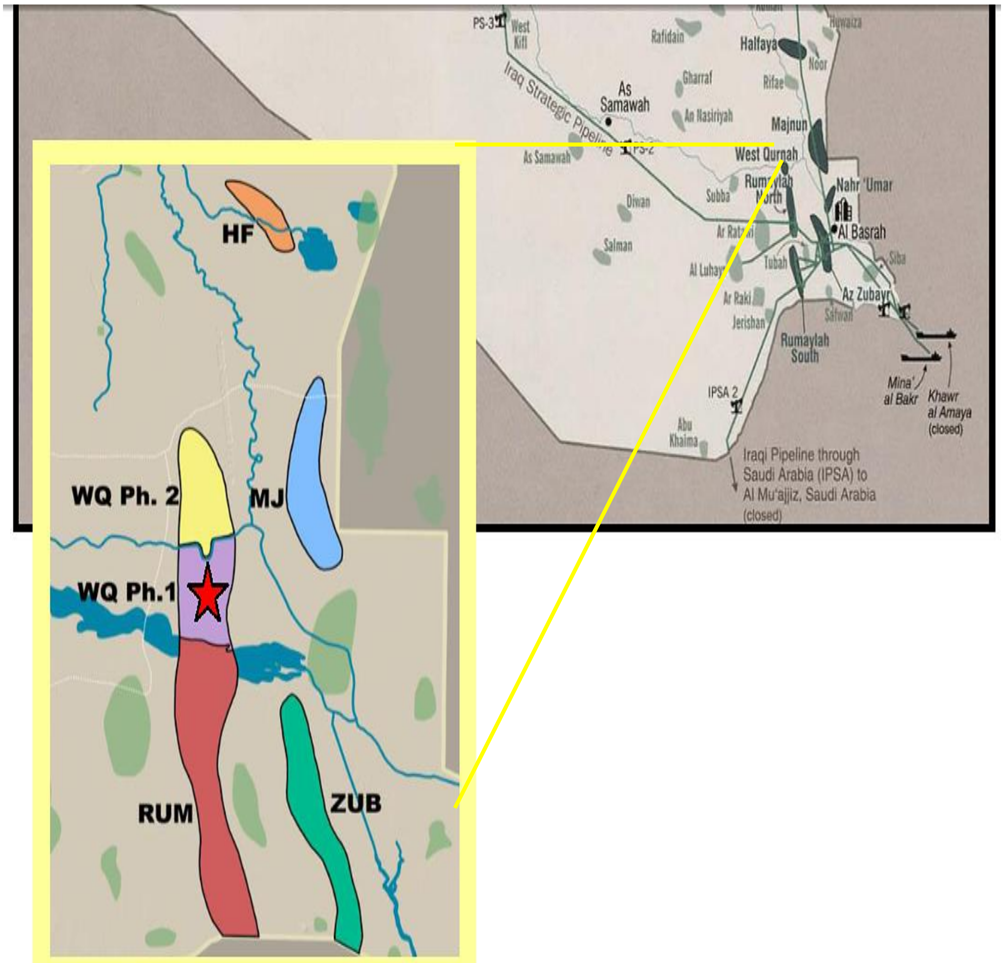

Figure 2: Location of West Qurna oilfield [24]

The Middle Cretaceous Age is the major carbonate reservoir in the southern Iraq oilfields. Mishrif carbonate formation represents this era (specified in general as heterogeneity and complexity), in which six main facies (varying from mid-ramp to supratidal facies) comprise the Mishrif Formation [25, 26] (Figure 3a). The Zubair succession, known as the Barremain sequence, is a part of the Late Tithonian-Early Turonian Mega-sequence. The formation was sedimental in a large intra-shelf basin synchronous with another tectonic era of the sea-floor composition. The declination and the eventual layers change in the Zubair Formation across horizontal faults (Figure 3b). The axis of this basin moved out from the eastern Mesopotamian zone into the Tigris subzone (Figure 4) [28, 29].

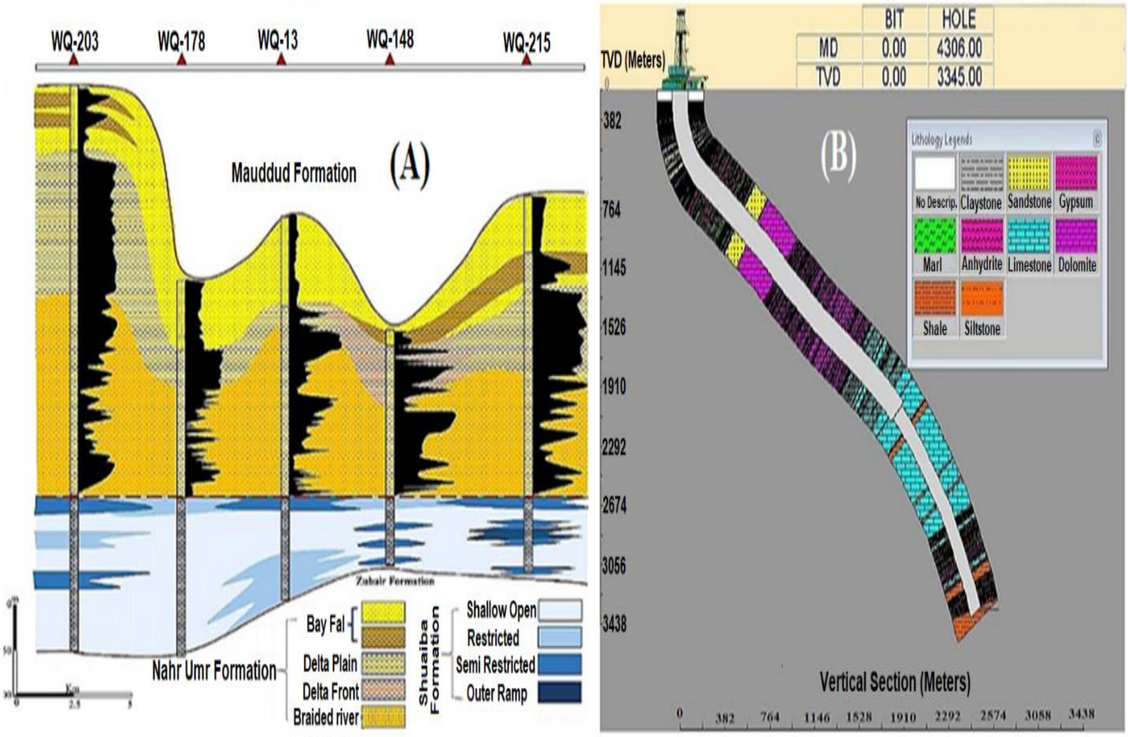

Figure 3: A- Cross-section for Zubair Formation in West Qurna oilfield for well WQ1-453 (By researchers) B- Facies changes for Mishrif Formation in the West Qurna oilfield [27]

2.1 Tectonic of Southern Iraq

The Iraqi region is divided into four main tectonic zones based on various factors such as rock types, age and thickness of the zones, and structural evolution. These zones are known as the Interior settled shelf, Exterior unsettled shelf (which lacks transitional types and volcanic activities), Shalair territories, and Zagros [30]. The main parts of the Mesopotamia foredeep in Iraq are the Mesopotamia and Jazira Plain, characterized as being less tectonically disturbing and have been formed from quaternary alluvial sediments of the Tigris and Euphrates Rivers and tributaries cover the central and southeastern parts of the basin clarifies the extension of the Mesopotamia Plain towards the northwest by wrapping Miocene rocks [31]. The Mesopotamia Basin is a flatted topography generally. The structures resulting from the tectonic actions are scarce in this basin, containing several structures, including faults, folds, and diapiric structures [32]. When the mud weight is lower than the fracture gradient, mud lost circulation can be avoided [33]. When two blocks move, this movement in different directions might produce three main fault types: Normal fault: the mass located over the fault has shifted downward while the mass below remains in its place. The main reason for this fault system is the extension. The Strike-slip fault: when two blocks slip in the way that one on another, a strike-slip fault exists. Reverse fault: when the upper block over the fault plane moves up and over the lower, that movement will make a reverse fault widespread in compression regions (Figure 4.) [34, 35].

2.2 Faults and folds in Mesopotamia Foredeep

The Mesopotamia Basin contains a set of normal-type faults. Fault trending systems can be recognized in two directions, extending from the north nest to the southeast and the other east-northeast to west-southwest [32]. The simple clasp folds are one of the significant fold types created from the regional compression by the impact of the Arabian-Eurasian plate. In general, these folds keep track of the direction of the Zagros fold toward the Thrust Belt. Another type is the least existent and does not pursue the Zagros fold trend characterized as limited to the extreme southern part of Iraq. Related to the salt movement based on the historic inherited North-South Arabian trend, this form of endeavor is best developed in the northern Gulf region. Thus, it is aptly called bending folds. Figure 5a shows that this type of fold is characterized by long, broad, and low amplitude folds, as seen in the Zubair and Rumaila Formations [36, 37, 38].

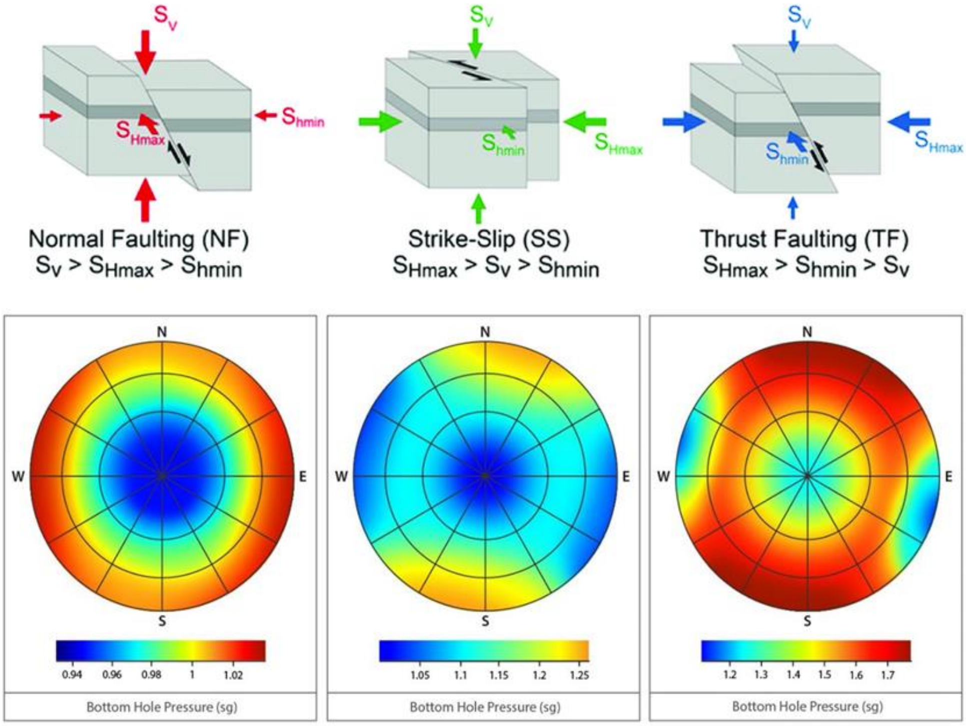

Figure 4: Fault system, stress regimes, Breakout development, and borehole stability

2.3 Tectono-stratigraphy of Passive Margin

Continental edges represent active and passive margins. The active is continental margins, which are seismically effective and match the neighboring plate borders. The passive margins develop at the edges of a fault following the rift-drift transformation, and they are described as having little seismic activity [39, 40] (Figure 5b). Two stages can recognize the history of the Mesopotamian passive margin: Divergent plate borders when the collection plates moved apart to represent the opening phase (Figure 6). The individual plates trended to each other creating the closing phase featuring convergent plate borders [41].

3. Materials and Methods

The data from thirteen wells (drilled from 2014 to 2016) for the West Qurna/1 oilfield recently were utilized in this study, in addition to data obtained from old wells. The current equations compute the three types of stresses [42, 43]:

$$\sigma_v = \rho_w g z_w + \int_{z_w}^{z} \rho g dz \quad (2)$$

$$\sigma_h = P_p + 0.77 \cdot (\sigma_v - P_p) \quad (3)$$

$$\sigma_H = 1.15 \cdot \sigma_h \quad (4)$$

The faulting system is Strike-slip calibrated to WBS and World Stress Map data, Pore pressure: Empirical normal compaction models. The term Equivalent circulating density (ECD) refers to the dynamic density calculation, especially during the circulation process of the drilling mud along the borehole. The (ECD) values calculated during the fluid influx at any time are still greater than the values of static mud density (SMD) when the flow stops [44]. Equation (1) will be utilised to estimate ECD.

$$\mathrm{ECD} = \frac{P_s}{0.052 \times TVD} + MW \quad (1)$$

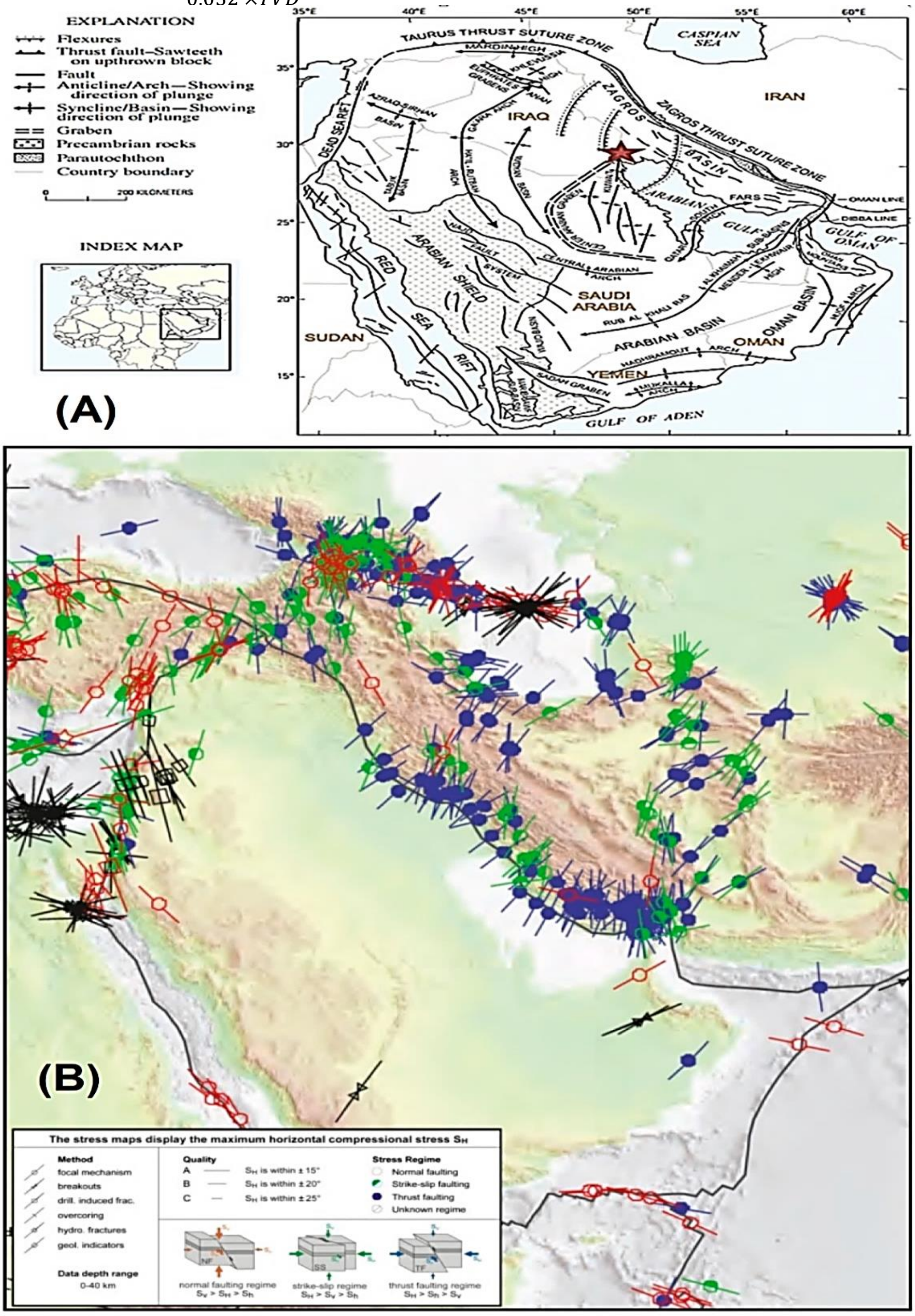

Figure 5: A- Map of Iraq with nearby geological features and full of tectonic activities indicated by faulting and folding [45], B- Tectono-stratigraphy of Passive Margin [44]

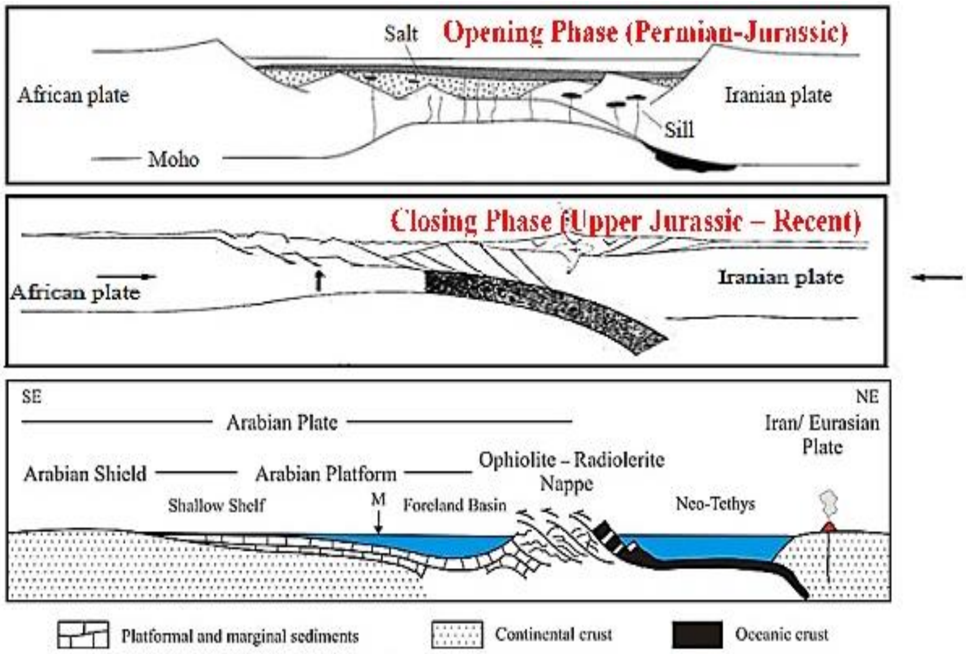

Figure 6: Tectono-stratigraphy of Passive Margin (Whole Iraq region) [46]

3.1 Major technical limitations and wellbore drilling problems in the West Qurna oilfield

For the current casing design, Tanuma or depleted Mishrif formations are in the same section of mud weight. Depleted wells in the Mishrif and Nahr-Umr formations are in the same section in a constrained mud-weigh. According to the current mud system, Wells drilled towards the minimum horizontal stress direction add wellbore stability problems like borehole collapse, voluminous caving, and string stuck, especially with the current limitation in water-based mud. The chemically and mechanically unstable shales in Tanuma, Nahr Umr, Upper, and Middle Shale Formations create devastation and are more sensitive to an azimuth and inclination. Severe instability can be noticeable in the Lower Fars and Ghar Formations, intermediate in the Dammam, Tayarat, UER, and Hartha formations. Stress direction was adjustable according to maximum horizontal stress to be at a maximum value of azimuth equal to 55 degrees based on the breakout and world stress map. The wells utilized in this study (Table 1).

Table 1: wells of the Mishrif and Zubair formations in the current study.

No.	Well Name	Target	Well Shape
1	**WQ1-XX7**	Mishrif	J-shape
2	**WQ1-XX9**	Zubair	S-shape
3	**WQ1-X40**	Zubair	J-shape
4	**WQ1-X41**	Mishrif	horizontal
5	**WQ1-X42**	Mishrif	J-shape
6	**WQ1-X43**	Mishrif	horizontal
7	**WQ1-X44**	Mishrif	horizontal
8	**WQ1-X45**	Zubair	J-shape
9	**WQ1-X46**	Mishrif	horizontal
10	**WQ1-X48**	Mishrif	J-shape
11	**WQ1-X50**	Mishrif	horizontal
12	**WQ1-X53**	Zubair	S-shape
13	**WQ1-X56**	Zubair	J-shape

Based on the maximum and minimum stress direction, the wells might be divided into two categories: Category I = 52 +/- 25 or 232 +/-25 degrees and Category II = 142 +/- 35 or 322 +/-35 deg (Figure 7). Figure 8 represents the distance between the wells versus measured depth, which separation is the actual distance between ellipsoids.

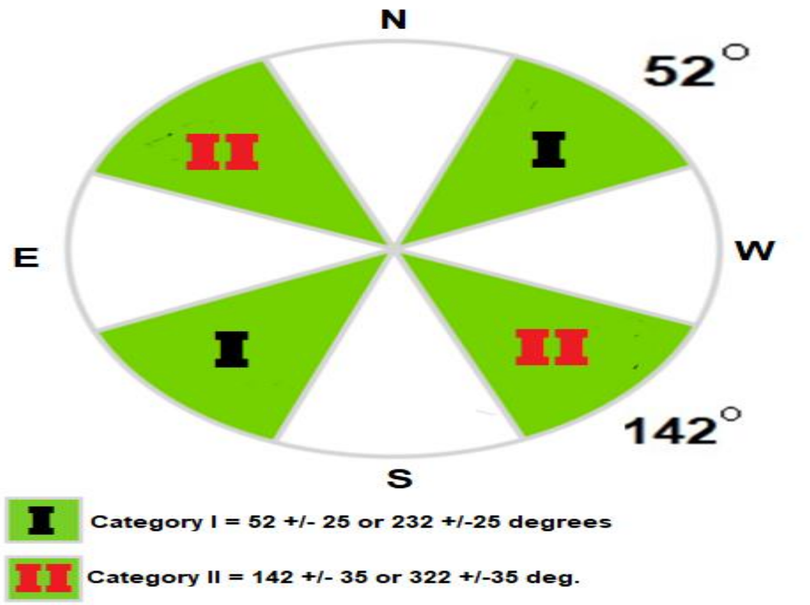

Figure 7: Well Trajectory Category

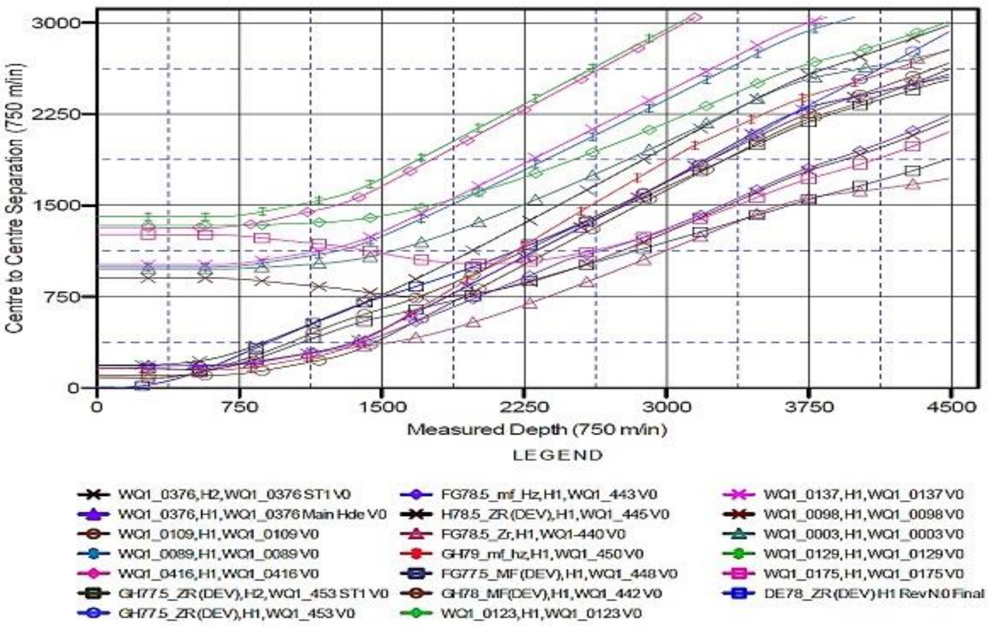

Figure 8: the distance between the wells versus the measured depth

4. Results

Group 1: West Qurna-1 oil wells sensitivity match with regional stress distribution (wells WQ1-XX1, XX2, XX3, and XX4) (Figure 9).

Group 2: Mishrif and Zubair Formations wells in the West Qurna-1 oilfield, which have been divided into two categories based on deviation and azimuth. The wells (Table 2) show different tendencies of WS according to the field data.

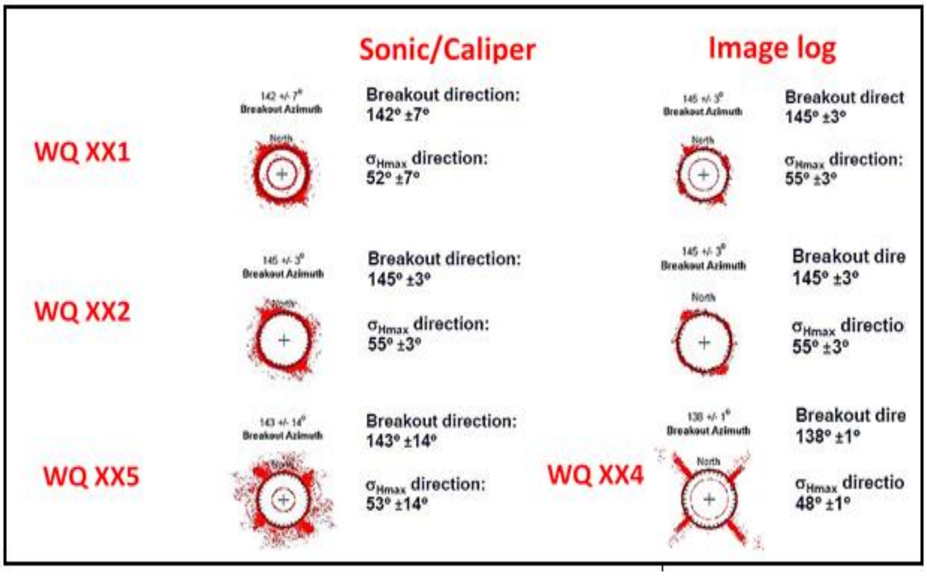

Figure 9: West Qurna-1 oil wells, which match Regional stress

Table 2: WBS for wells under study

No.	Well Name	Target	Category	Deviation (deg.)	Azimuth (deg.)	Remarks
1	**WQ1-XX7**	Mishrif	II	17	92	No WBS Issue
2	**WQ1-XX9**	Zubair	II	22	89	Severe WBS problem
3	**WQ1-X40**	Zubair	II	25	6	Severe WBS problem
4	**WQ1-X41**	Mishrif	II	14	340	No WBS Issue
5	**WQ1-X42**	Mishrif	I	45	30	No WBS Issue
6	**WQ1-X43**	Mishrif	II	40	5	WBS problem, Liner stuck
7	**WQ1-X44**	Mishrif	II	15	0	No WBS Issue
8	**WQ1-X45**	Zubair	I	34	46	No direct WBS problem
9	**WQ1-X46**	Mishrif	II	34	148	Good hole
10	**WQ1-X48**	Mishrif	II	48	356	No WBS Issue
11	**WQ1-X50**	Mishrif	II	27	16.5	No WBS Issue
12	**WQ1-X53**	Zubair	I	43	27	No WBS Issue
13	**WQ1-X56**	Zubair	II	18	319	Severe WBS problem

Figure 10 explains the mud weight differential window for Zubair Formation wells in West Qurna with different degrees of drilling cases. Figure 11 illustrates the comparison between wells WQ1-X53 (Eastern flank) and WQ1-X56 (western flank) using mud weight data and equation 4 and the comparison between wells WQ1-X50 (Eastern flank) and WQ1-X43 (western flank) using mud weight data and equation 1. Figure 12. Shows WBS for regional stress versus mud weight across all the limestone formations that the Well (WQ1-X56) trajectory passes through. While Figuure-13 illustrates WBS for shale formations.

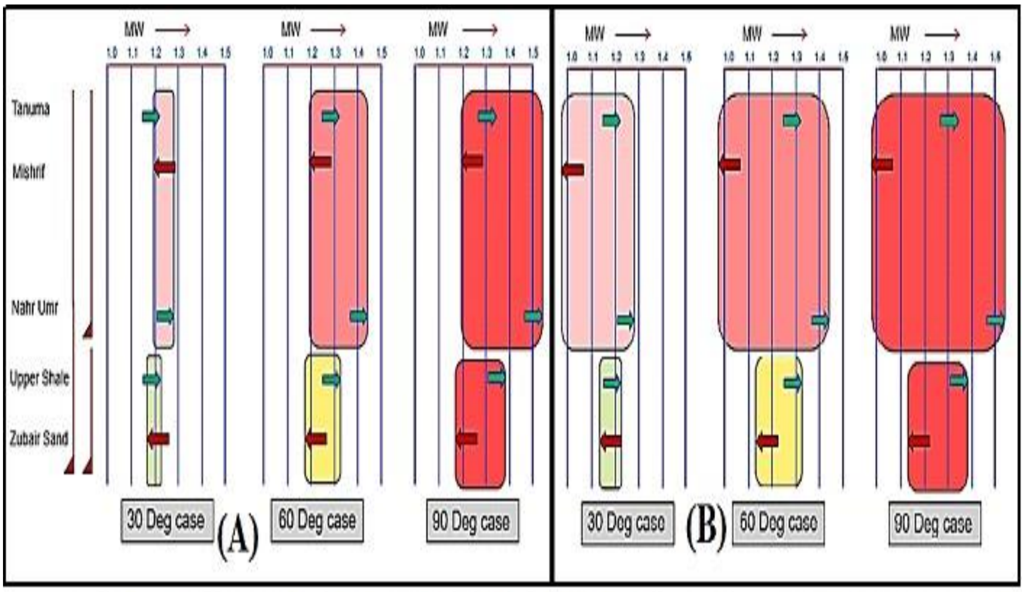

Figure 10: Mud Weight differential window for Zubair Formation wells in West Qurna oil field: A-Initial, B- Current phase

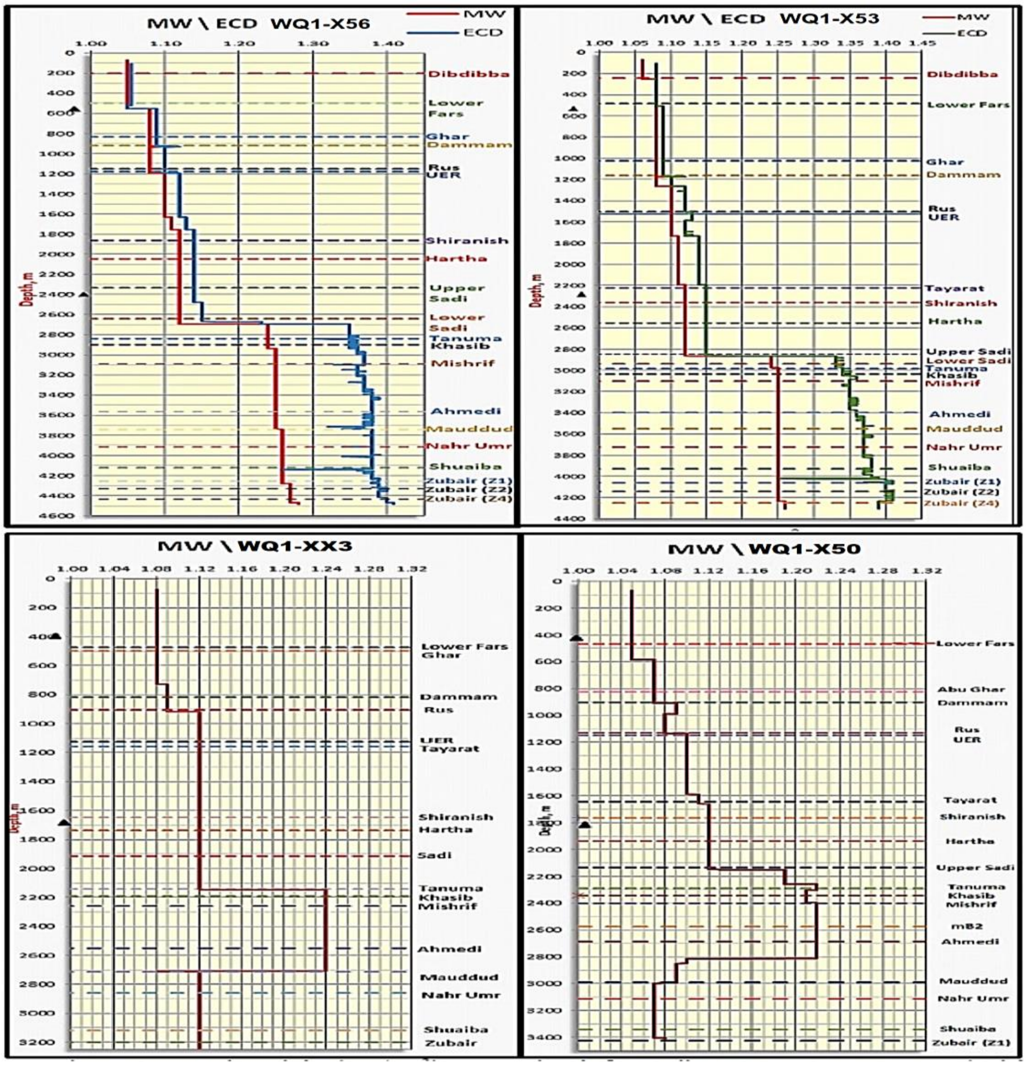

Figure 11: Mud weight and ECD (gm/cm3) versus depth for wells WQ1-X53, WQ1-X56 (Zubair Formation) and mud weight (gm/cm3) versus depth for wells WQ1-XX3, WQ1-X50 (Mishrif Formation)

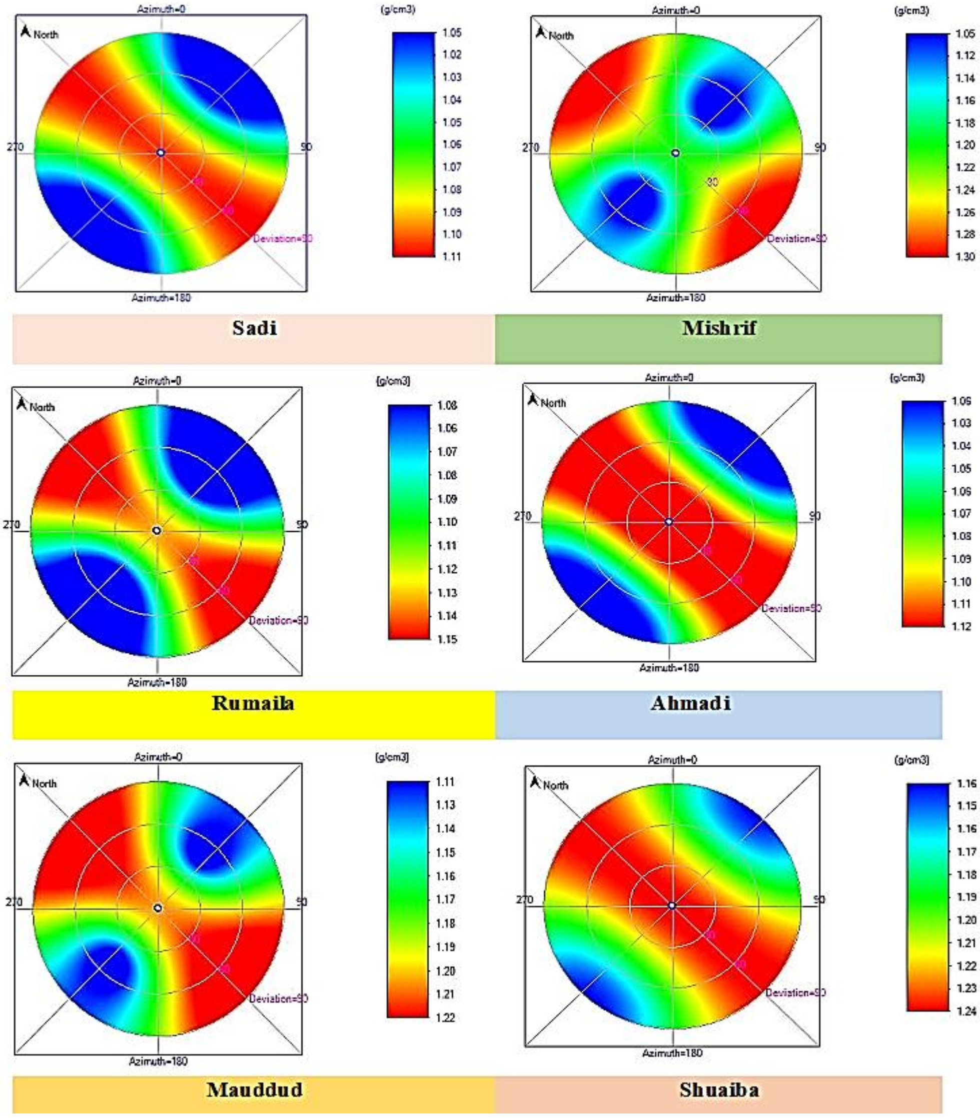

Figure12: WBS plot for regional stress versus mud weight for limestone formations Well WQ1-X56.

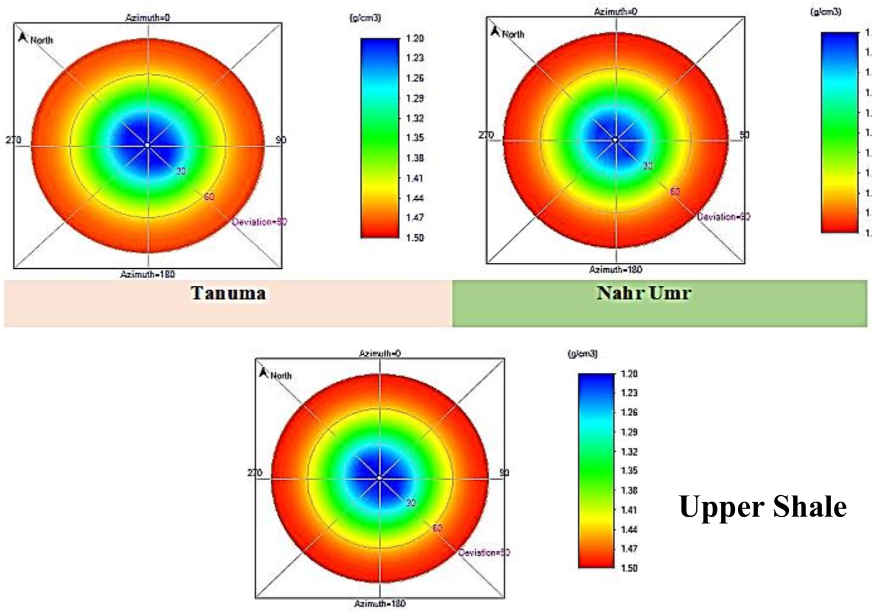

Figure 13: WBS plot for shale formations for Well WQ1-X56.

The minimum mud weight (from top formation to bottom) required to achieve good WBS in WQ1-X56 is summarized in Table 3.

Table 3: Minimum mud weight required for WBS in WQ1-X56 Injection well

Formation Name	S_v , S_h , and S_H correlation	Possible fault type	Min. MW required for WBS in gm/cm^3
Sadi	$S_v \geq S_H \geq S_h$	Normal	1.10
Tanuma	$S_H \geq S_h \geq S_v$	Reverse	1.24
Mishrif	$S_H \geq S_v \geq S_h$	Strike-Slip	1.25
Rumaila	$S_v \geq S_H \geq S_h$	Normal	1.11
Ahmedi	$S_v \geq S_H \geq S_h$	Normal	1.13
Mauddud	$S_v \geq S_H \geq S_h$	Normal	1.20
Nahr Umr	$S_H \geq S_v \geq S_h$	Strike-Slip	1.39
Shuaiba	$S_v \geq S_H \geq S_h$	Normal	1.14
Zubair Upper Shale	$S_H \geq S_v \geq S_h$	Strike-Slip	1.29

From Figure 14, it is clear that the stress regime of the well WQ-XX9 is normal faulting for sandstone and shale membrane in the Zubair Formation with less horizontal stress variation, while a strike-slip faulting regime exists in the limestone Formation (Mishrif).

5. Discussion

Table 2 demonstrates that the overall trajectory distribution in the (Q-I) scenario is improving the performance of the well. A combination of the deviation and azimuth represents the Well performance, but the Mishrif Formation wells in the West Qurna/1 oilfield are less sensitive than Zubair wells to direction and azimuth. Observation shows that the Mishrif Western flank is more prone to mud loss than the eastern flank, which may be due to the presence of a major fracture.

By comparison with the results obtained from the Zubair oilfield (Table 4) and Rumaila oilfield (Table 5), it is clear that category (I) (52 +/- 25 or 232 +/-25 deg for Azim.) is the best condition for drilling wells in both Mishrif and Zubair formations.

Table 4 : WBS for the Mishrif and Zubair Formations wells in the Zubair oil field

Well Name	Category	Deviation (deg.)	Azimuth (deg.)	Remarks
ZUB-1M	I	45	240	Good well
ZUB-2M	I	45	197	less problem
ZUB-3M	II	31	157	Severe WBS problem
ZUB-4M	II	60	282	Side track
ZUB-5Z	I	19	70	less problem
ZUB -6Z	II	17	200	less problem
ZUB -7Z	II	24	144	Side track
ZUB -8Z	II	20	17	Side track
ZUB -9Z	II	26	335	Severe WBS problem
ZUB -10Z	I	21	36	less problem

* Category I = 52 +/- 25 or 232 +/-25 degree and Category II = 142 +/- 35 or 322 +/-35 deg

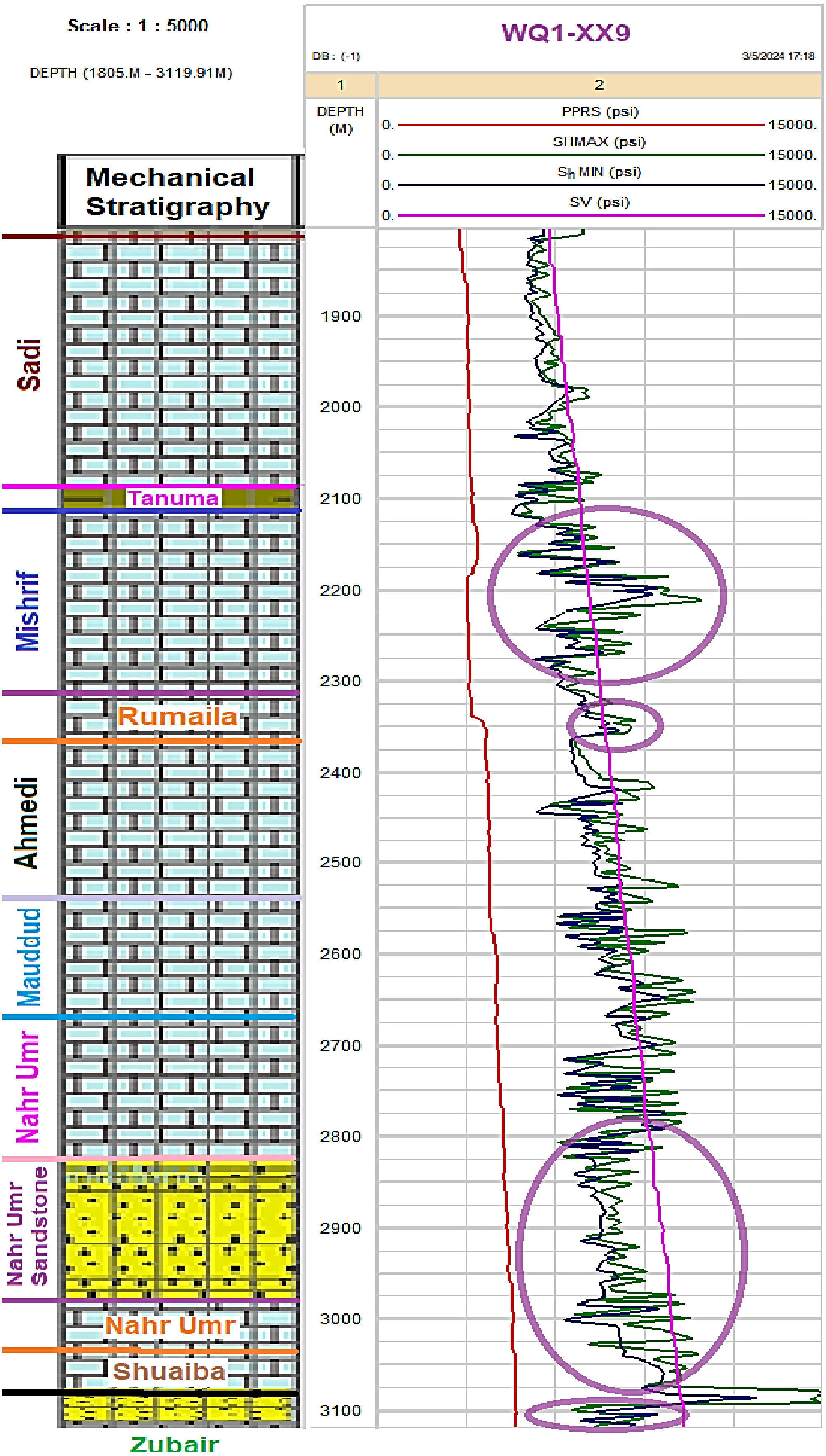

Figure 14: Categories of the Well WQ1-XX9 according to the maximum and minimum Stress direction

Table 5: WBS for the Zubair Formation wells in the Rumaila oil field

Well Name	Category	Deviation (deg.)	Azimuth (deg.)	Remarks
R-11Z	I	11	75	No WBS issue
R-12Z	II	22	27	Casing reciprocation
R-13Z	I	28	67	Good hole, and a few tight spots
R-14Z (S)	II	32	164	25-30 klbs over pull, Caving
R-15Z (S)	I	28	217	No WBS issue
R-16Z	I	26	232	Good hole
R-17Z	II	21	265	Lot of trips, hole cleaning
R-18Z	II	18	321	Tool stuck, back reading
R-19Z	I	27	57	Good hole
R-20Z	I	27	60	No WBS issue
R-21Z	I	17	70	Best hole record

6. Conclusions

1. Mishrif wells are less critical than Zubair wells in terms of pore pressure optimization in an alternative depleted reservoir and geo-pressurized shale sequence.
2. Drilling high-angle Zubair wells is particularly challenging due to the lengthy tangent section. S-shaped wells have greater stability compared to J-shaped wells. The stability of Mishrif wells with an S-shape configuration is generally worse compared to J-shape and horizontal wells.
3. All the wells drilled towards maximum horizontal stress like WQ1-XX5, WQ1-XX2, and XX3 show minimal wellbore stability problems. The well WQ1-X53 is planned towards NE direction whereas WQ1-X56 is towards a very critical & challenging azimuth with high deviation.
4. The average maximum horizontal stress direction is 55 +/- 20 and 235 +/-20 degrees is better than 142 +/- 35 or 322 +/-35 deg.
5. The Mishrif Formation wells are considered less mud loss in the eastern flank than the western flank of the field. The mud loss is a critical issue that has been seen in the wells WQ1-XX0 and X56. The Mishrif wells are lowly sensitive to azimuth and deviation, but the Zubair formation wells are highly sensitive to azimuth and inclination.
6. The maximum horizontal stress direction is the most recommended direction to reduce well complexity and challenging drilling environment.
7. A formation prognosis with lithology and expected wellbore stability pressures is required to determine the drilling window to consider while drilling in the West Qurna 1 field.

Nomenclature

Deg. Degree
ECD Equivalent circulating density (gm/cm^3)
ENE east-north-east
FEM Finite Element Method
FG Fracture gradient
g gravitational constant
Hf Halfaya oilfield
Inj. Injection

Klbs Kilo pounds
Max. Maximum
Min. Minimum
Mj Majnon oilfield
MW Mud weight
P_p Pore pressure (Psi)
P_S Pressure drop in the annulus between TVD and surface (Psi)
psi pounds per square inch
NW north-west
R Rumaila oilfield
RF Recovery Factor
Rum Rumaila oilfield
SE south-east
SMD Static mud density (gm/cm^3)
TVD True vertical depth (meters)
UER Umm-erdhma formation
WBM water-based mud
WBS Wellbore stability
WQ West Qurna oilfield
WSW west-south-west
Z depth (meters)
ZUB Zubair oilfield
Z_w Depth of fluid column (meters)
σH maximum horizontal stress (Psi)
σh minimum horizontal stress (Psi)
σv vertical stress (Psi)
ρ_w Density of the fluid column as a function of depth (gm/cm^3)

Disclosure and conflict of interest

"Conflict of Interest: The author declare that they have no conflicts of interest."

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