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Stress Regime of Rumania Oilfield in Southern Iraq from Borehole Breakouts

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Abstract: *Rumaila oilfield is the largest subsurface structural anticline in the southern Mesopotamia Plain of Iraq. It consists of two culminations these are the North and South Rumaila with N-S and NW-SE fold axes, respectively. Borehole breakouts data from Image-logs of 90 wells in the Mishrif Formation within Rumaila oilfieldwere used to derive the stress pattern.The World Stress Map shows no data within the study area. This study aims to contribute in adding borehole breakouts data of the Rumaila oilfield to the map and correlate this data with the data from other oilfields within the Iraqi-Iranian border. Results of this study show that the direction of the horizontal maximum stress axis at the North Rumaila is 358° and South Rumaila is 351°.These results depict that the maximum stress axes are not perpendicular to the fold axis.The stress axes havean inclined angle of 7°at North Rumaila and 10° at SouthRumaila. These differences suggested being as a result of the anticlockwise rotational angle of the Arabian plate that is about 8°.This rotation might be responsible for the displacement on the Strike-slip movement on the Hammar Fault that divides Rumaila into North and South culminations.*

Keywords: *Rumaila oilfield, Stress pattern, Borehole breakouts, Mesopotamia Plain, Rotation of the Arabian Plate.*

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I. Introduction

Rumaila oilfield, which was discovered in 1953, is the most important field in the southern part of Iraq. It is locatedabout 45km west ofBasrah city between zones 47°14'46" - 47°26'14" Easting and 31°12'41" - 30° 05'5.7" Northing within the Mesopotamia Foredeep of Iraq (Figure 1). Rumaila oilfieldis surroundedby prominently narrow and elongated subsurface anticlines; these are Zubair, NahrUmr, Artawi, Tuba, and Luhais.These subsurface anticlines are oilfields trend N-S (Figure 2). Mishrif and Zubair Formations are the main reservoirs in Rumaila oilfield.

This study focus on analyzing the stress regime that effects on the Rumaila field from borehole breakouts.The results of this study will help to fill the gap of stress direction in southern Iraq that can be seen clearly in the World Stress Map (WSM)(Figure 3). In addition, knowing the stress directions can be used to study the movement directions on the faults in the study area.

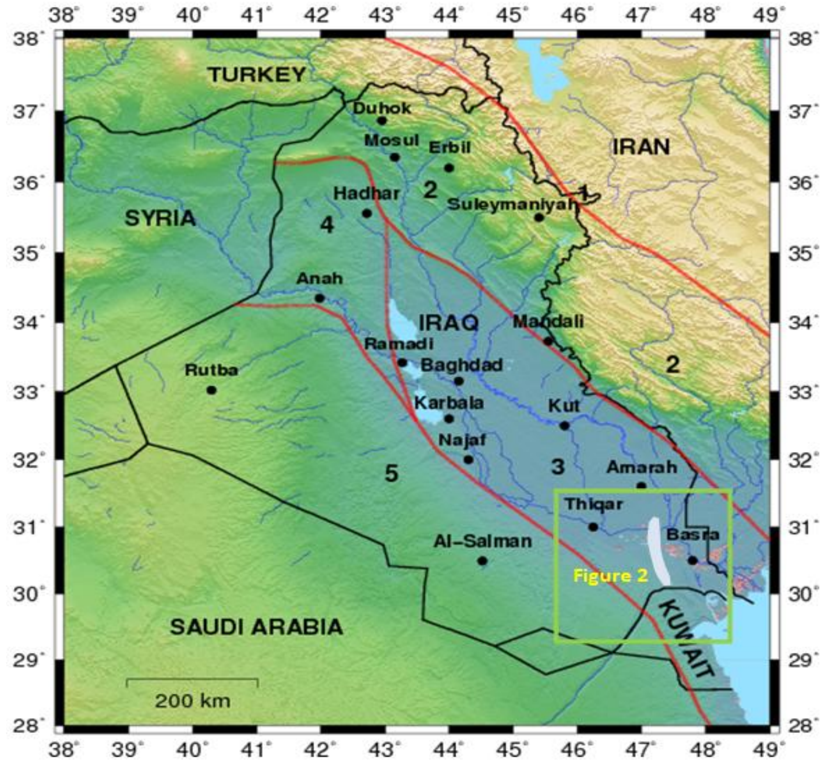

Figure 1: The tectonic division of Iraq modified from Fouad (2010), Fouad and Sissakian (2011), and Sissakian *et al.* (2017). 1 Shalair Terrance; 2 Zagros Fold-Thrust Belt; 3 Mesopotamia Plain; 4 Al-Jazira Plain; 3 and 4 Mesopotamia Foredeep; 2, 3, and 4 Outer Unstable Platform; 5 Inner Stable Platform. Green rectangle representsboundaries of Figure 2.

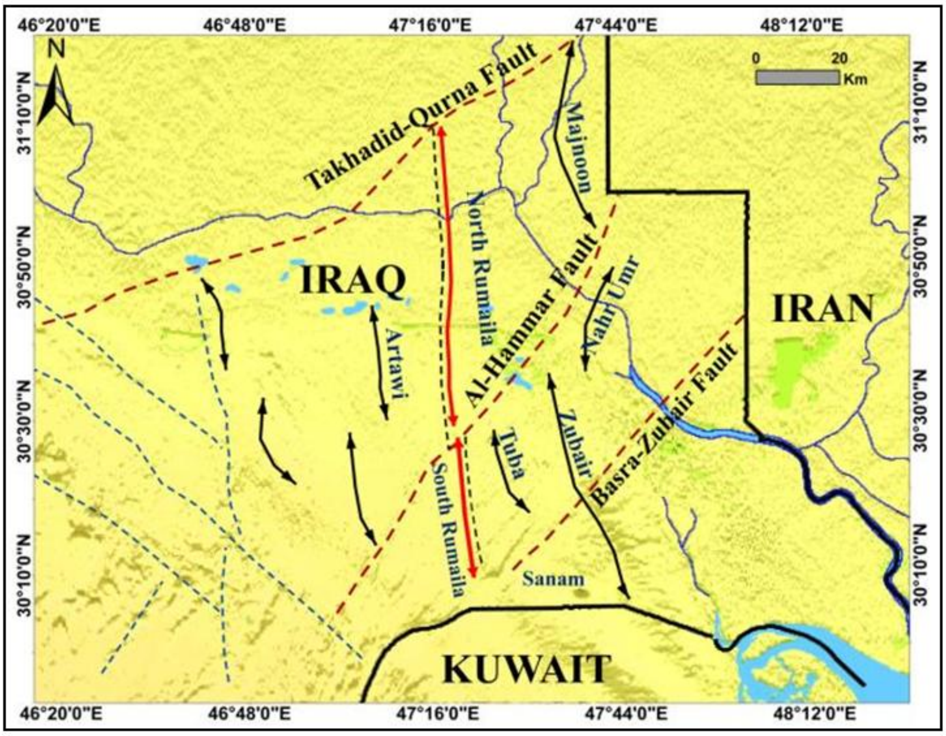

Figure 2: Location of Rumaila oilfield and nearby surroundingoilfieldswithin the Zubair Subzone. The red broken lines are transversal faults and the black broken lines are longitudinal faults that are usually parallel to the fold axes of the subsurface anticlines(Jaffar, 2018).

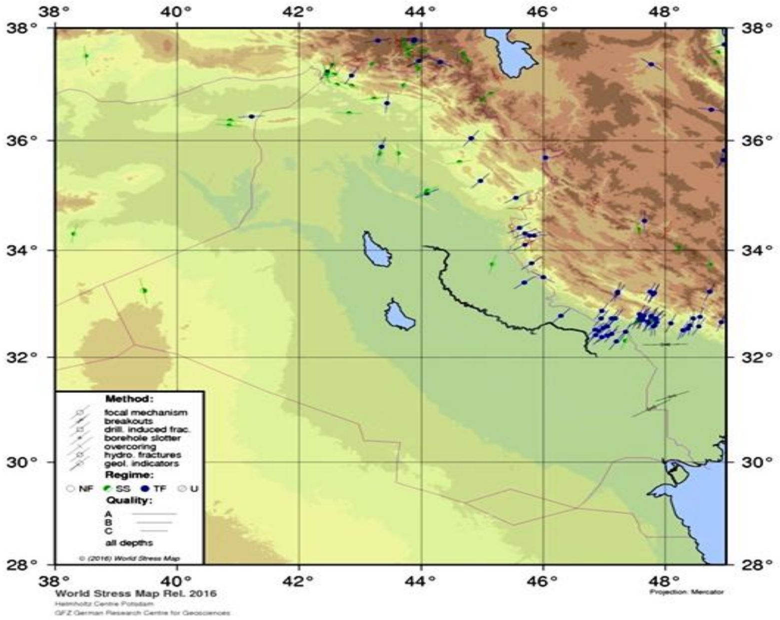

Figure 3: Stress map for Iraqand surrounding regions plotted by the website of the World Stress Map. All data within the region are derived from the focal mechanism solutions with a few exceptions that derived from the borehole breakoutsand can be seen at southeastern borders of Iraq with Iran. There is no stress data in southern Iraq.

Geology of Rumaila oilfield

According to Fouad (2010), Rumaila oilfieldis locatedwithinthe Mesopotamia Plain that is part of the MesopotamiaForedeep basin (Figure 1).The Mesopotamia Plain is a flat terrain, slopping very gently toward the Persian Gulf. It has subsurface complex structures like folds, faults, and salt structures. These subsurface structures are entirely hidden beneath the Quaternary cover and represent important oilfields in the middle and southern Iraq. Besides these structures, there are high and complex stratigraphic columns containing the deferent types of sedimentary rocks. The area characterized by the existence of many gently plunging subsurface structures of different sizes that usually have a very poor reflection of the surface relief (Karim, 1989,1992, 1993; Aqrawi*et al*., 2010).

In the extreme southern part of the Mesopotamia Plain, which called the Zubair Subzone according to Buday and Jassim(1987), the trend of subsurface folds is N-S. Almost all of the subsurface anticlines in the Mesopotamia Plain are gentle folds with interlimb angles of 170° and dip of limbs < 5°. The long anticlines such as the Zubair and Rumaila are non-cylindrical folds with two or three culminations (Abdulnaby and Al-Mayahi, 2010).

The amplitudes of the N-S trending structures of the Zubair Subzone increase with depth and reach ~ 300 m at the Lower Cretaceous level. The structures are long and relatively narrow anticlines separated by broader synclines especially in the east. Shorter and oblique trending structures also exist. The most prominent narrow elongated antiforms are the Zubair and the Rumaila structures. Shorter and often-broader structures include NahrUmr, Majnoon, Rachi, Ratawi, Subba and Luhais. The Zubair Subzone is the most productive petroleum region in Iraq (Figure 2).

The Takhadid-Qurna Fault forms the N boundary of the Zubair Subzone and the Hormuz salt basin of Iraq. It consists of a series of faults trend NE-SW that defined on the gravity gradient maps. It is a basement fault formed during the Precambrian and has a down-throw towards the southeast (Jassim and Göff, 2006). Hammar and Basrah-Zubair Faults are other two faults that are located inside the Zubair Subzone and parallel to the Takhadid-Qurna Fault (Figures 2).

Only the upper part of the Paleozoic sequence had been penetratedby drilling in the Mesopotamia Foredeep. The Paleozoic sequence consists prominently of siliciclastic sediments deposited in a shallow epicontinental sea. The Mesozoic sequence of the area increases from the west to the east to be around 5 km. This sequence starts with Triassic evaporites, shales and carbonates of neretic to lagoonal nature, passes upwards into an open and shallow marine carbonates with subordinate evaporites of Jurassic age, which isGotnia Formation, then altered to carbonates and sandstones, followed by Cretaceous open marine carbonates that represented by theYammama, Zubair, and Mishrif Formations. The Cenozoic sequence is mainly contained of Paleogene open marine carbonates, which representedby Umm-erradhuma, Rus, and Dammam Formations,that grades up into a Neogene lagoonal and restricted marine evaporitic facies, followed by deltaic molasse type and continental clastics, which represented byGhar and Lower Fars Formations(Alsharhan and Nairn, 1997; and Sharland*et al*., 2001).

The stratigraphic column of Rumaila structure contained entirely from sedimentary rocks (Figure 4). The Mesozoic sediments represent the main source rock and reservoir in southern Iraq including Rumaila field. TheSulaiy Formationrepresents the source rocks, while the Yamamma, Zubair, NahrUmr, Mishrif, and Lower Fars Formations represent the reservoir rocks. The Zubair Formation is the main producing zone in the Rumaila oilfield. It was deposited in Early to Middle Cretaceous (Barremian) with 300 m to 450 m thick(Owen and Nasr, 1958; Nairn and Alsharhan, 1997; Jassim and Göff, 2006; Fouad, 2010).

Table 1: Formation tops in Rumaila oilfield from well (Ru-441) (ROO, 2014).

Formation	Depth (m)
Dibdibba	Surface
Lower Fars	162.0
Ghar	279.0
Dammam	430.0
Rus	660.0
Umm Er-Radhuma	829.0
Tayarat	1279.0
Shiranish	1539.0
Hartha	1626.0
Sadi	1799.0
Tanuma	2168.0
Khasib	2213.0
Mishrif	2257.0
Rumaila	2400.0
Ahmadi	2475.0
Moudud	2622.0
Nahr Umr	2732.0
Shuaiba	3000.0
Zubair	3093.0

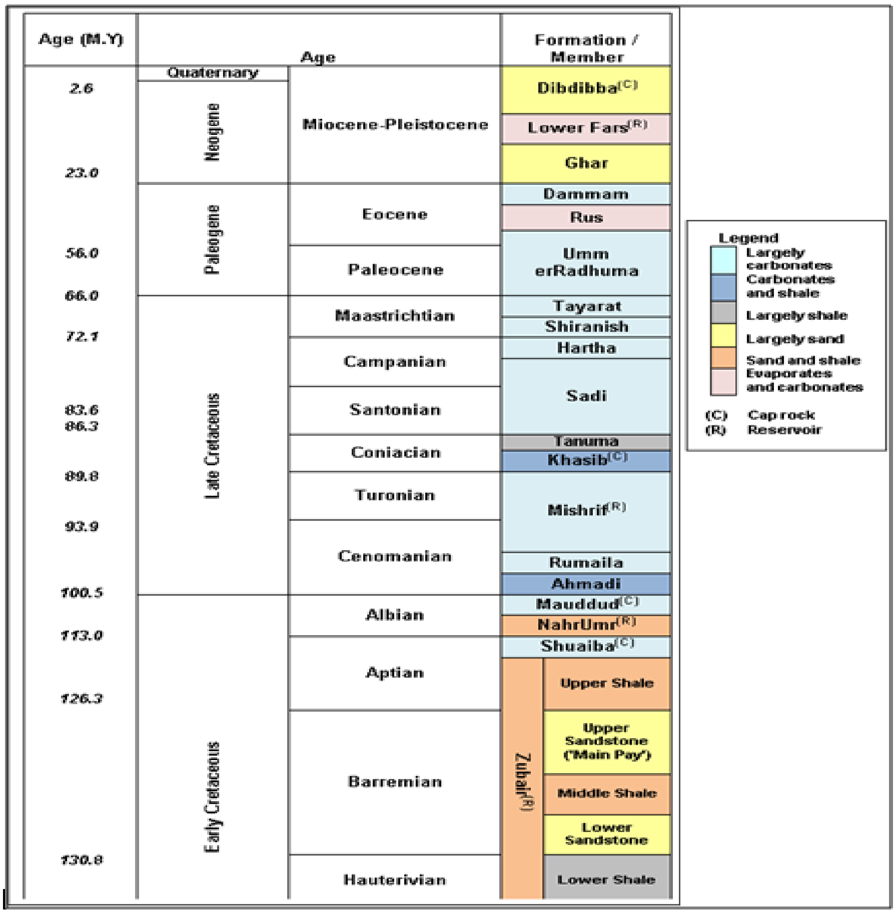

Figure 4: Stratigraphic column in Rumailaoilfield(Owen and Nasr, 1958).

Genetically, many researchers suggested that there are three main reasons combined to create Rumaila anticline; these are theAlpine orogeny, basement uplift, and salt mechanism that is represented by the Infra-Cambrian Hormuz salts(Abdulnaby,2003; Al-Najar, 1989).

The length of Rumaila oilfield is 117km and its width around 20km. Geometrically, the structure can be classified asasymmetrical, linear, gentle, horizontal, upright, and shallow anticline. The fold axis of the North Rumaila culmination trends N-S, while the South Rumaila culminationtrends NW-SE (Table 2). North and South Rumaila culminationsare separatedby a distinctive depression (Saddle) associated with Hummar Fault (Jaffar, 2018). The North Rumaila culmination has a shallow depression at the northern part of it. Therefore, most of the oil companies tend to consider Rumaila anticline having three culminations instead of two. The three culminations are West Qurna, North Rumaila, and South Rumaila. As it is suggested in this study, the Rumaila anticline has only two culminations because the shallow depression on the North Rumaila culmination is not changing the geometrical analysis of the culmination (see Table 2).

Table 2: Geometrical analyses of the three culminations of Rumaila oilfield. The analyses depict the attitudes of the western and eastern limbs of the anticline, the interlimb angle, and the azimuth or the trend of the fold axis.

Rumaila Field (Mishrif Fm.)	**Western Limb STRIKE / DIP**	**Eastern Limb STRIKE / DIP**	**Interlimb angle**	**Fold axis STRIKE / DIP**
West Qurna	178° / 1.99°	358° / 2.26°	175.75°	358° / 89.9°
North Rumaila	178° / 3.22°	358° / 1.46°	175.32°	358° / 89.1°
South Rumaila	171° / 1.75°	351° / 2.23°	176.02°	351° / 89.8°

As it was mentioned earlier, three main basement faults within Rumaila oilfield inferred from both gravity and seismic section (Figure 5). These faults arethe Takhadid-Qurna, Hammar, and Basrah-Zubair Faults.The North Rumaila culmination is located between the Takhadid-Qurna and the Hammar Faults, while the South Rumaila culmination is located between the Hammar and Basrah-Zubair Faults. In the other words, the Hammar Fault separates the North culmination from the South culmination (Figure 2). These three faults are part of the Transversal Fault Systems in Iraq that may have formed in Late Precambrian times and were reactivated from Late Jurassic times. The transversal faults in Iraq significantly affect the subsurface structure, especially on the top of the Precambrian basement (Jassim and Göff, 2006).

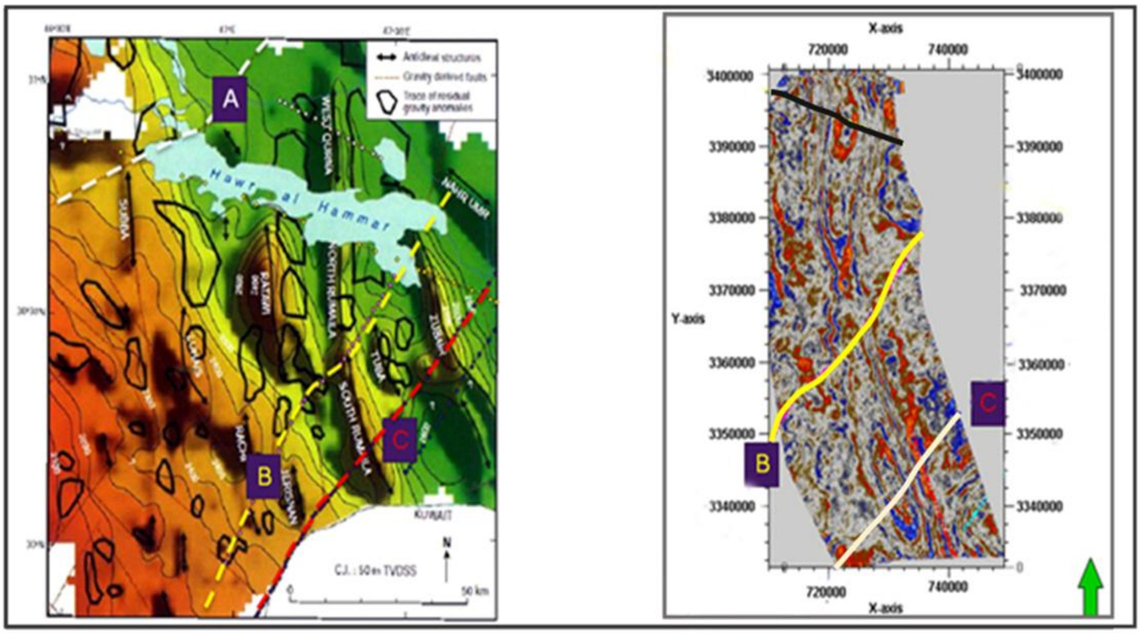

Figure 5: Basement faults in the Zubair subzone shownfaults across Rumaila oilfield.The left panel is a gravity map after (Jassim and Göff, 2006). The right panel is a seismic map. A Takhadid-Qurna Fault, BHammar Fault, and C Basrah-Zubair Fault.

II. Data and methodology

Image logs datafrom formation Full-boreMicro-Imager tool (FMI)of 90 wells from both North Rumaila and South Rumaila structure within the Mishrif Formationwere used to determine the stress regime within the measurements of the drilling breakouts method (Figure 6). Breakouts direction represents the direction of the Minimum horizontal stress axis(S_{hmin})within the area,which makes the Maximum horizontal stress axis (S_{Hmax}) perpendicular to breakouts orientation(Zang and Stephansson, 2010).S_{Hmax} can be seen on image logs by a pair of black smears in the log, while S_{hmin} appeared as a tensile splitting, which also known as the Drilling Induced Tensile Fracture (DITF) (ROO, 2014) (Figure 7). Breakouts data was collected and then plotted byusing the Generic Mapping Tool(GMT) software(Table 3).

Table 3: Wells used for stress analyses showing breakouts direction (azimuth) within the Mishrif Formation.

WELL	X	Y	AZI (Breakouts direction)		WELL	X	Y	AZI (Breakouts direction)
R-062z	47.31	30.68	96		Ru-344	47.32	30.41	25
R-511	47.31	30.64	12		Ru-348	47.36	30.30	121
R-512	47.32	30.61	5		Ru-350	47.33	30.35	270
R-513	47.31	30.52	164		Ru-352	47.32	30.38	251
R-514	47.34	30.61	166		Ru-353	47.35	30.35	50
R-515	47.32	30.47	97		Ru-354	47.34	30.30	311
R-516	47.31	30.53	238		Ru-355	47.35	30.34	15
R-518	47.32	30.59	268		Ru-356	47.34	30.37	234
R-519	47.34	30.62	205		Ru-357	47.34	30.36	318
R-520	47.33	30.60	256		Ru-358	47.38	30.22	220
R-522	47.32	30.56	227		Ru-360	47.37	30.28	64
R-523	47.33	30.43	3		Ru-361	47.39	30.32	62
R-524	47.33	30.45	260		Ru-367	47.38	30.27	32
R-525	47.30	30.56	216		Ru-368	47.38	30.29	84
R-526	47.31	30.62	20		Ru-369	47.36	30.32	72
R-528	47.30	30.52	208		Ru-370	47.35	30.36	62
R-529	47.30	30.57	244		Ru-373	47.37	30.31	83
R-530	47.30	30.62	267		Ru-374	47.39	30.27	64
R-531	47.30	30.57	272		Ru-378	47.36	30.33	69
R-532	47.30	30.57	277		Ru-379	47.38	30.28	49
R-533	47.34	30.56	147		Ru-380	47.37	30.30	64
R-534	47.32	30.53	140		Ru-381	47.41	30.18	84
R-535	47.32	30.63	109		Ru-382	47.41	30.19	89
R-536	47.33	30.48	80		Ru-385	47.42	30.24	62
R-537	47.32	30.48	67		Ru-387	47.34	30.37	21
R-540	47.30	30.62	43		Ru-388	47.40	30.20	48
R-541	47.33	30.48	82		Ru-389	47.39	30.26	58
R-544	47.35	30.48	111		Ru-390	47.40	30.23	67
R-545	47.30	30.62	109		Ru-391	47.39	30.26	68
R-548	47.3	30.7	67		Ru-392	47.39	30.25	59
R-550	47.30	30.57	255		Ru-393	47.38	30.28	79
R-553	47.29	30.57	270		Ru-394	47.42	30.20	97
R-554	47.55	31.05	150		Ru-395A	47.38	30.26	76
R-556	47.29	30.56	332		Ru-396	47.38	30.24	93
R-560	47.33	30.47	89		Ru-397	47.38	30.24	25
Ru-250z	47.41	30.18	116		Ru-398	47.36	30.35	88
Ru-254z	47.44	30.14	91		Ru-402	47.36	30.34	76
Ru-317	47.32	30.41	313		Ru-404	47.38	30.25	46
Ru-324	47.34	30.41	35		Ru-407A	47.40	30.21	114
Ru-325	47.34	30.42	120		Ru-412	47.41	30.23	62
Ru-328	47.33	30.40	251		Ru-426	47.38	30.24	225
Ru-334	47.38	30.31	65		Ru-431	47.37	30.42	128
Ru-335	47.38	30.30	75		Ru-347	47.34	30.38	53
Ru-339	47.33	30.39	238		Ru-359	47.36	30.31	89
Ru-341	47.35	30.40	60		Ru-371	47.37	30.30	43
Ru-343	47.32	30.42	264		Ru-386	47.40	30.22	77

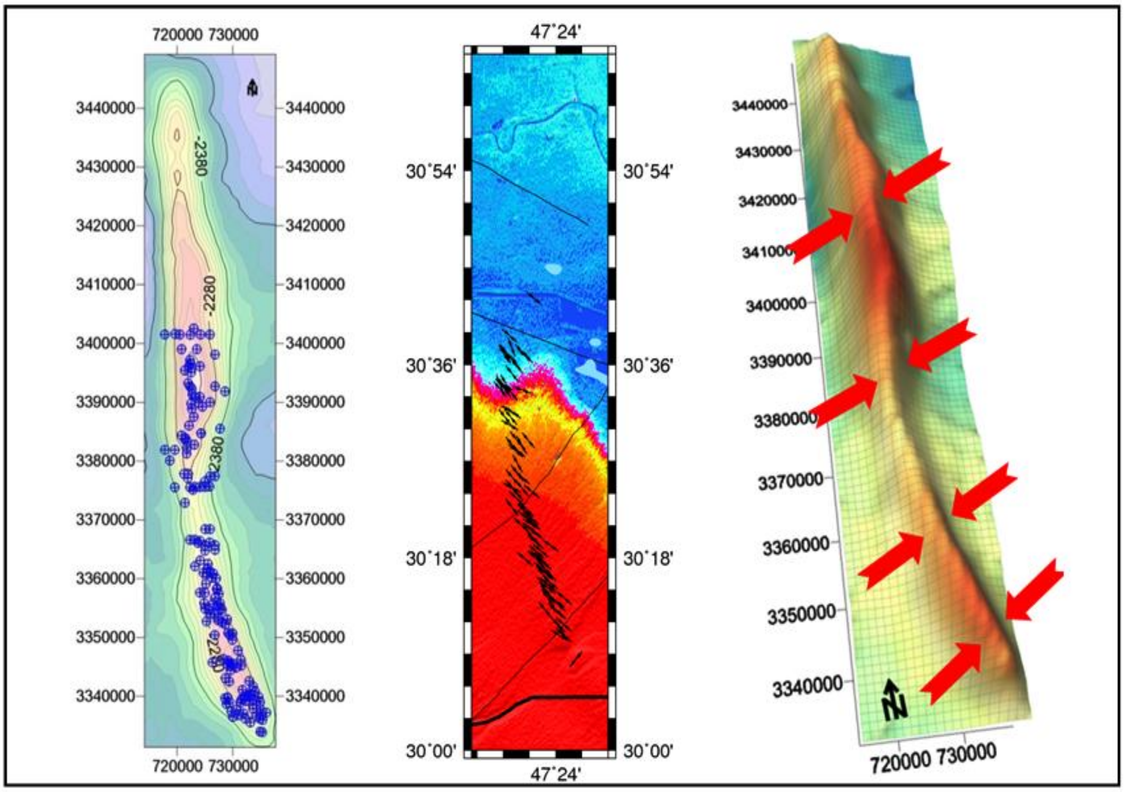

Figure 6: Stress map from borehole image logs. The left panel is the location of wells that used in this study plotted on the Mishrif structural contour map. The middle panel is the borehole breakouts directionsderived from image logs interpretations.The right panel is the maximum horizontal stress S_{Hmax} affecting Rumaila oilfield (red arrows).

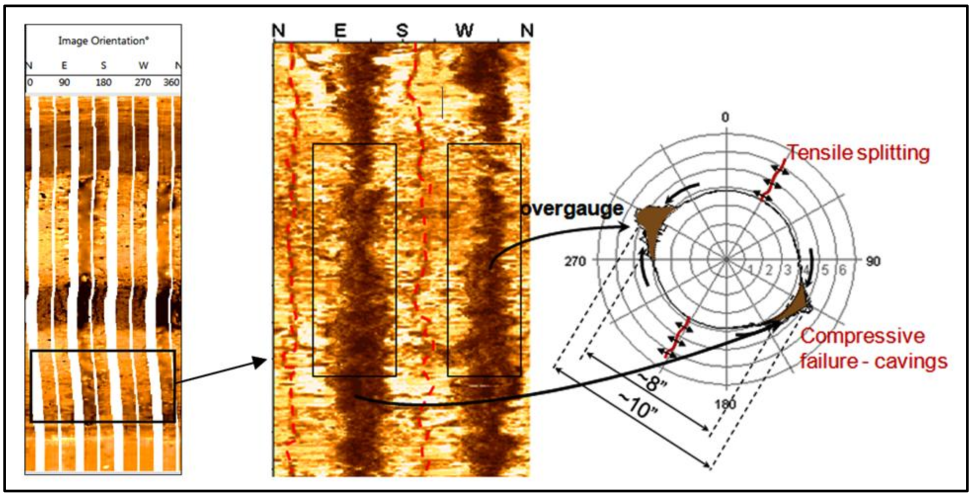

Figure 7: Image logs from well Ru-431 shows vertical black smears due to borehole enlargements (breakouts)(ROO, 2014).

Stress regime within Rumaila oilfield

According to Anderson (1951),there is a simple threefold classification of fault sets based on the three possible orientations of the stress axes; these are the normal fault sets, the strike-slip fault sets, and the thrust fault sets. Figure 8 shows the relations between the three fault sets and the principal stress axes, which are the

Maximum horizontal stress axis (S_{Hmax}), the Minimum horizontal stress axis (S_{hmin}), and the Vertical stress axis (S_V).

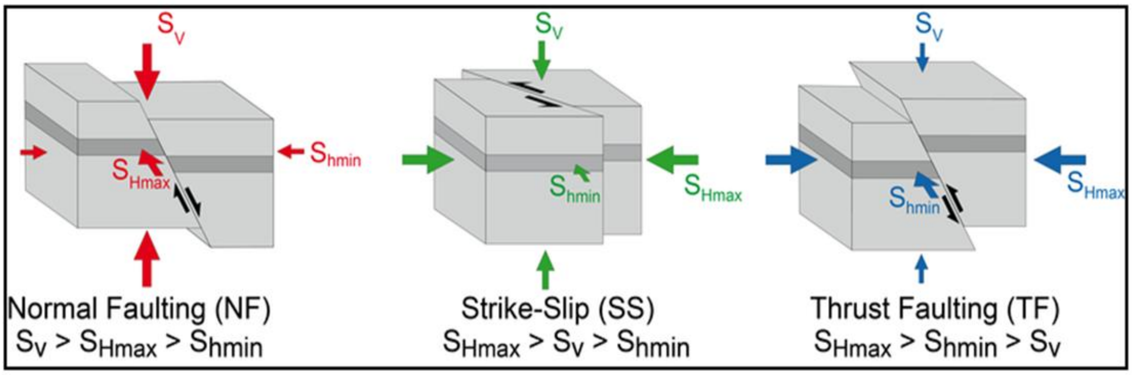

Figure 8: Anderson fault types. For normal faults, the vertical stress is the largest principal stress. For strike-slip faults, the vertical stress is the intermediate principal stress. For the thrust faults, the vertical stress is the smallest principal stress(Heidbach*et al.*, 2016).

The collision between the Arabian and the Iranian plates led to the strike-slip regime within the study area with NW-SE direction. Data from image logs showed that there is a systematic regime within the field in both the North and the South Rumaila with the same trend of NW-SE that corresponds with the Zagros trend.

As previously mentioned,the trends of North and South Rumaila fold axes are 358^0 and 351^0 ,respectively, which make the theoretical maximum horizontal stresses affecting on each culmination are 268^0 and 261^0 , respectively, because the theoretical maximum horizontal stresses must be perpendicular to the fold axis (Ramsay, 1967; Fossen, 2010).This study shows that theaverage S_{Hmax} axes obtained from borehole breakouts are deviated in both North and South Rumaila culminations by 7^0 and 10^0 , respectively from the theoretical S_{Hmax} axes (Figure 9).

Hancock and Atiya (1979) suggested the anticlockwise rotation of Arabia from fractures analysis. Numan(1984) concluded from the displacement of strike-slip faults in the basement a rotational movement of the basement rocks. Subsequently, Numan (2000) showed that Alpine continental collision of the Arabian Plate started with the collision with the Turkish Plate and later proceeded to collide with the Iranian Plate. This collision implies an anticlockwise rotation of Arabia.The Arabian plate rotation and collision generates strike-slip faultswithin the Zubair Subzoneresulting in a shear stress within the basement faults.

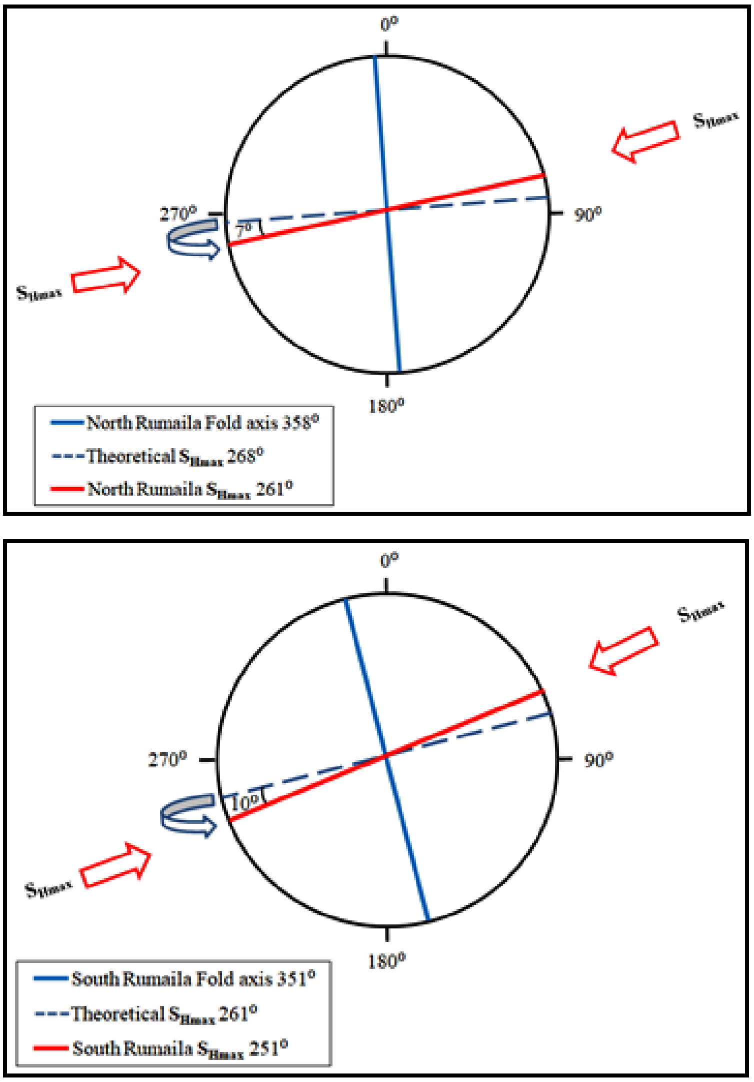

Figure 9: The differences between the theoretical and calculated S_{Hmax}. The upper panel shows that the North Rumaila S_{Hmax} axis deviated by 7^0 from the theoretical S_{Hmax}. The lower panel shows the South Rumaila S_{Hmax} axis deviated by 10^0 from the theoretical S_{Hmax} axis. These differences are due to the anticlockwise rotation of the Arabian plate.

The results of stress data will make a good contribution to the World Stress Map data. Figure 10 is a zoomed map depicts thatboth Azadeganoilfield in Iran and Rumaila oilfield have nearly the same stress pattern, which suggests that the Zubair Subzone is extended to beyond the Iraqi border.

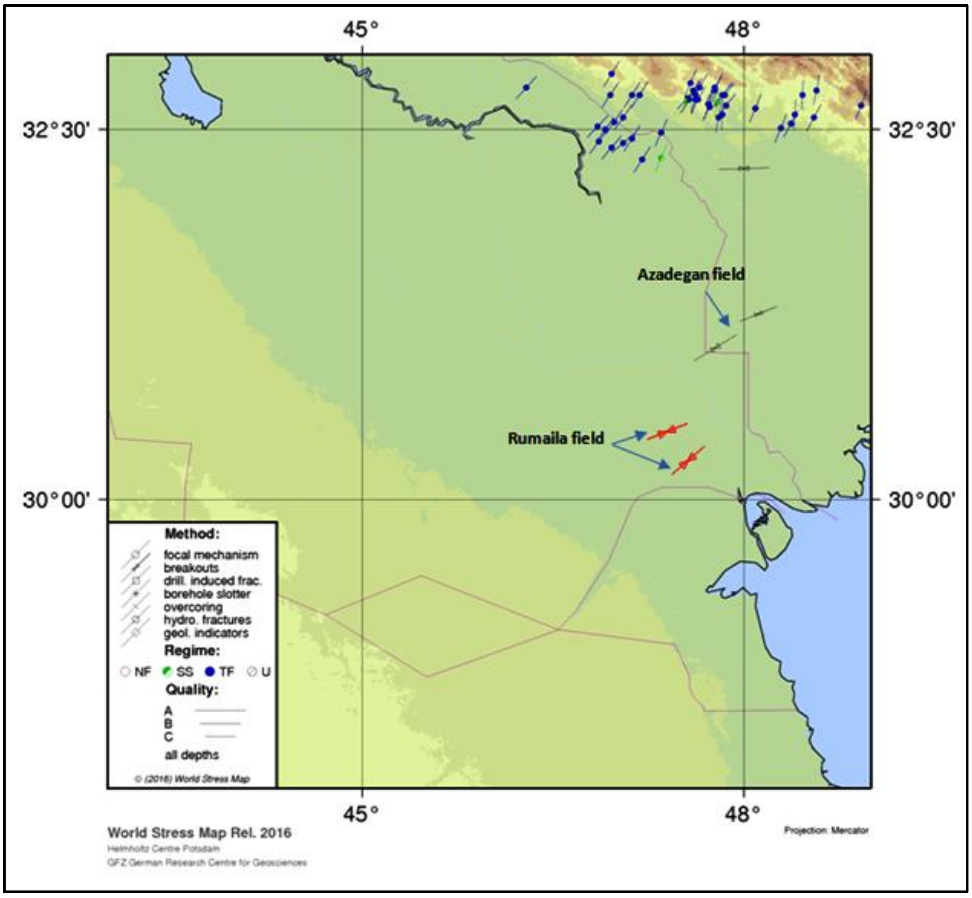

Figure 10: Rumaila oilfield stress (Red breakouts) on the World Stress Map and nearby stress regime from Azadeganoilfield in Iran.

III. Discussion

From the structural analyses andthe stress pattern of Rumaila oilfield, the Zubair Subzone, which is bounded by the Takhadid-Qurna Fault in the NW and the Basrah-Zubair Fault in the SE, can be subdivided into two parts; these are the North and South Zubair Subzone,which are separated by the Hammar Fault. The North Rumaila culmination is located within the northern part of the Zubair Subzone, while the South Rumaila culmination is located within the southern part. The two culminations are separated by the Hammar Fault, which plays an important role in changing the direction of fold axis of Rumaila structure.

From this study, the Hammar Fault is a left-lateral strike-slip fault that is having its displacement as a result of the anticlockwise rotation of Arabia. In fact, the strike-slip displacements in the basement rocks of Iraq result from the fact that collision started when the northern part of the Arabian Plate hit the Turkish Plate first. With geological time, the collision continued and closed the remaining Neo-Tethys Ocean with scissors like the closure of the Neo-Tethys and inevitable anticlockwise rotation of Arabia. Later on, Arabia collided eventually with Iran.

The calculated maximum horizontal stress axes show 7^0 and 10^0 from the directions of fold axes of North and South Rumaila culminations respectively. It is suggested that this inclination has been formed as a result of the anticlockwise rotation of the Arabian Plate;because, without this rotation, the calculated maximum horizontal stress axes should be perpendicular to the fold axis of the Rumaila anticline. More structural subsurface studies need to be carried out in order to shade more light on the role of the rotation of Arabia on the displacements of the basement faults in the Zubair Subzone.

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