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Wellbore Breakouts Prediction from Different Rock Failure Criteria

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ABSTRACT

One of the wellbore instability problems in vertical wells are breakouts in Zubair oilfield. Breakouts, if exceeds its critical limits will produce problems such as loss circulation which will add to the non-productive time (NPT) thus increasing loss in costs and in total revenues. In this paper, three of the available rock failure criteria (Mohr-Coulomb, Mogi-Coulomb and Modified-Lade) are used_to study and predict the occurrence of the breakouts. It is found that there is an increase over the allowable breakout limit in breakout width in Tanuma shaly formation and it was predicted using Mohr-Coulomb criterion. An increase in the pore pressure was predicted in Tanuma shaly formation, thus; a new mud weight and casing programs are proposed to overcome such problems in the drilling operations in field developments plans.

Keywords: Zubair Oilfield, wellbore instability, Breakouts prediction, Failure Criteria, Nonproductive time reduction, casing design.

توقع التكسرات في التجويف البئري باستخدام معايير فشل صخور مختلفة

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الخلاصة

تعتبر التكسرات (التوسعات) التي تحدث في جدران الابارالنفطية الشاقولية احدى المشاكل الشائعة اثناء عمليات الحفر في حقل الزبير النفطي. فقدان دورة سائل الحفر هي من اخطر المشاكل المتوقعة اذا تم تجاوز الحد المسموح به لهذه التكسرات و بالتالي زيادة الوقت الغير منتج. تم استخدام ثلاث معايير لفشل الصخور (مور-كولومب، موكي-كولومب و ليد المعدلة) لدراسة و توقع حصول التكسرات. بناءا على نتائج تحليل البيانات، تم تشخيص منطقة فشل تجاوزت الحد الاقصى في طبقة التنومه ذات محتوى الطفل العالي و تم التنبؤ بها عن طريق معيار مور-كولومب. تم التنبؤ بزيادة في الضغط المسامي في طبقة التنومه لذلك،تم اختيار طين حفر وبرنامج تبطين جديدين في المنطقة ذات المشاكل العالية حيث يعتبر كحل امثل لمواجهة هذه المشاكل في خطط التطوير المستقبلية.

الكلمات الرئيسية: حقل الزبير النفطي، تكسرات التجاويف البئرية، عدم ثبوتية الابار، تقليل الوقت الغير منتج، تصميم البطانة.

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1. INTRODUCTION

Breakouts are one of the common wellbore stability problems in vertical wells. Breakout is spalling of the rocks from the circumference of the wellbore (**Gough and Bell**, **2017**); (**Zoback, *et al.*, 2003**). Breakout occurs in three stages, namely; breakout initiation, breakout propagation and breakout stabilization **(Olcott, et al., 2013)**; (**Moore, *et al.*,** **2012**); (**Cheatham**, **1993**); **(Zheng, et al., 1989**). Initiation of breakouts occurs due to concentration of stress around part of the wellbore circumference. Flowing of drilling fluid adjacent to the wellbore wall region is the cause of breakout propagation and stabilization (**Cheatham, 1993**). Breakouts consumes time and costs a lot to be treated and fixed, therefore will increase in the drilling operations time thus in the overall NPT (**Li and Gray**, **2017**). In vertical wells, breakout starts to develop in the direction of the maximum stress concentration which is parallel and the same direction and orientation as the minimum horizontal stress (**Gough and Bell**, **2017**); (**Zoback, *et al.*, 2003**). Furthermore, breakouts usually analyzed depending on the linear elasticity assumption (**Gough and Bell**, **2017**); (**Zoback, *et al.*, 2003**); (**Zhou, 1994**). **(Gholami *et al.*, 2014)** studied different failure criteria on wellbore stability and mud window determination. **(Mohammed and Salman, 2019)** studied the possibility of diagnosing the problems that cause instabilities in the wellbore and suggested solutions by building 1D mechanical earth model (1D MEM). This study comes to the conclusion that Mohr-Coulomb criteria gave good results in vertical wells.

2. METHODOLOGY

2.1 Breakout Prediction:

The process of breakout profile prediction starts with detecting the existence of breakouts via the available X-tended Range Micro Imager, interpreted using Paradigm's Geolog 18 and Schlumberger's Techlog 2018 software (XRMI) resistivity image logs (highlighted in green in **Fig. 1**).

Figure 1. XRMI image log shows obvious breakouts, (**final well drilling reports, 2011**).

The next step is to model the breakout width profile using Baker Hughes's Jewelsuite Geomechanics 2018 software. Breakout width is the arc distance from the start to the end of the breakout around the borehole circumference.

Breakout width calculation is an iterative process. First, the three stresses (Overburden, Minimum and Maximum horizontal) must be computed at the depth of interest. Second, plot these three stresses in Mohr diagram and use the selected failure criteria to decide whether a failure exist or not and move to the next angle until the full circumference or half of the circumference because breakouts are symmetrical, completes at a certain depth. Finally, the breakout width is the angle difference between the start and the stop of the failure as shown in **Fig. 2**.

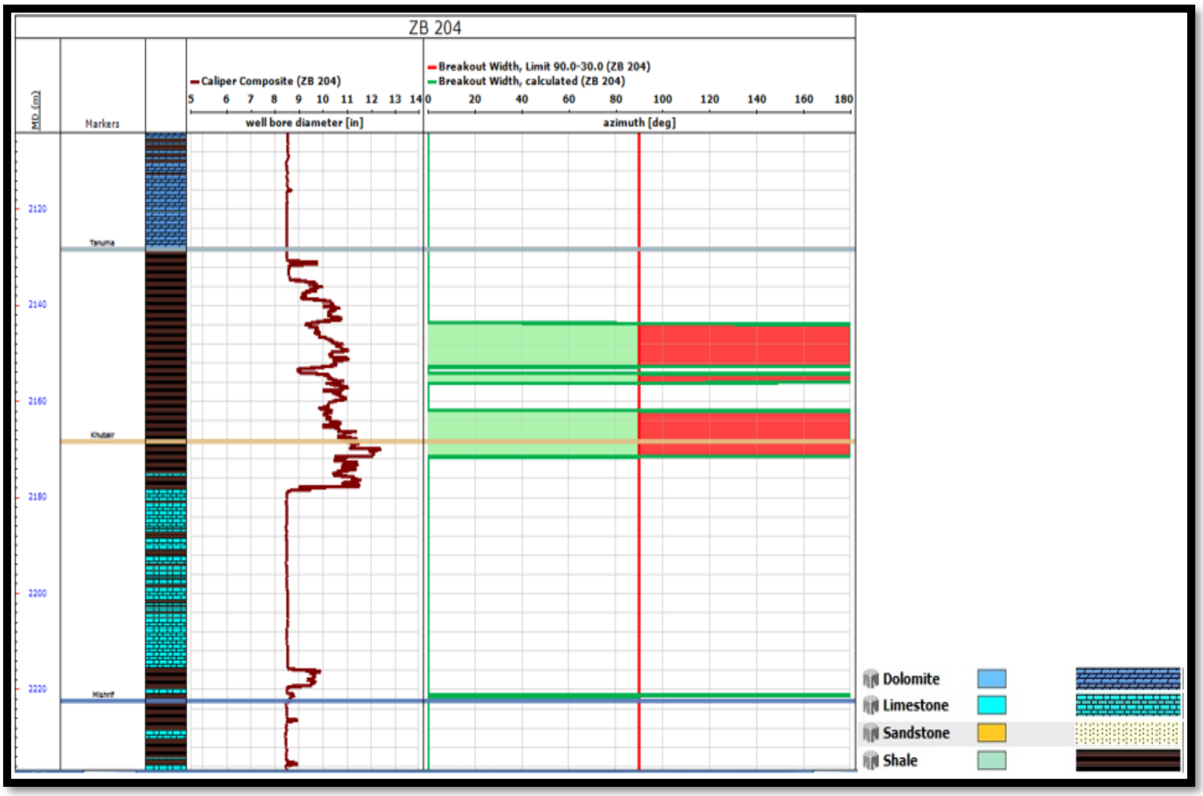

Figure 2. Predicted breakout width profile.

The breakout azimuth profile also created with respect to the north to match with the observed breakouts as illustrated in **Fig. 3**.

Combining the results shows the predicted breakouts at the same depth. Breakouts that exceeded the critical limit of 90^{o} occurred at Tanuma shaly formation (**Fig. 4**).

Plotting wellbore breakouts as a function of mud weight on the x-axis and rock strength on the y-axis (**Fig. 5**), at depth of around 2168 m and at a rock strength of almost 6.8 MPa by increasing the mud weight from 12.5 ppg to 13 ppg (less than 1 ppg) will reduce the breakout width to acceptable value.

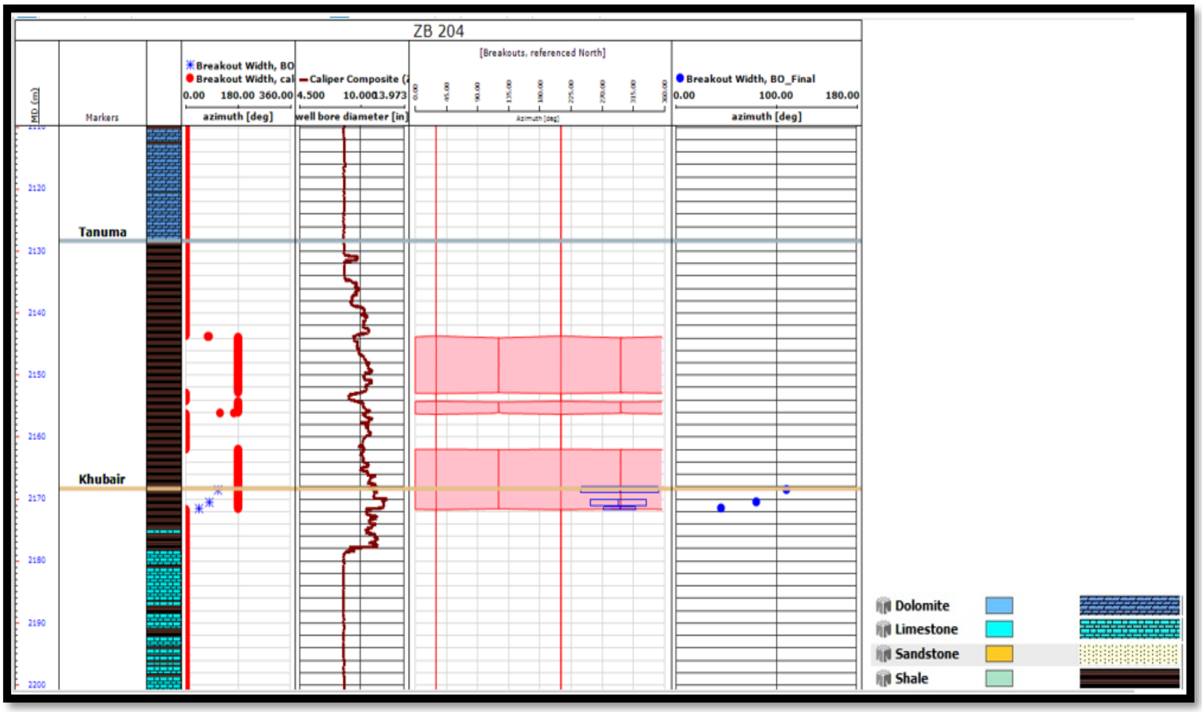

Figure 3. Breakout azimuth profile.

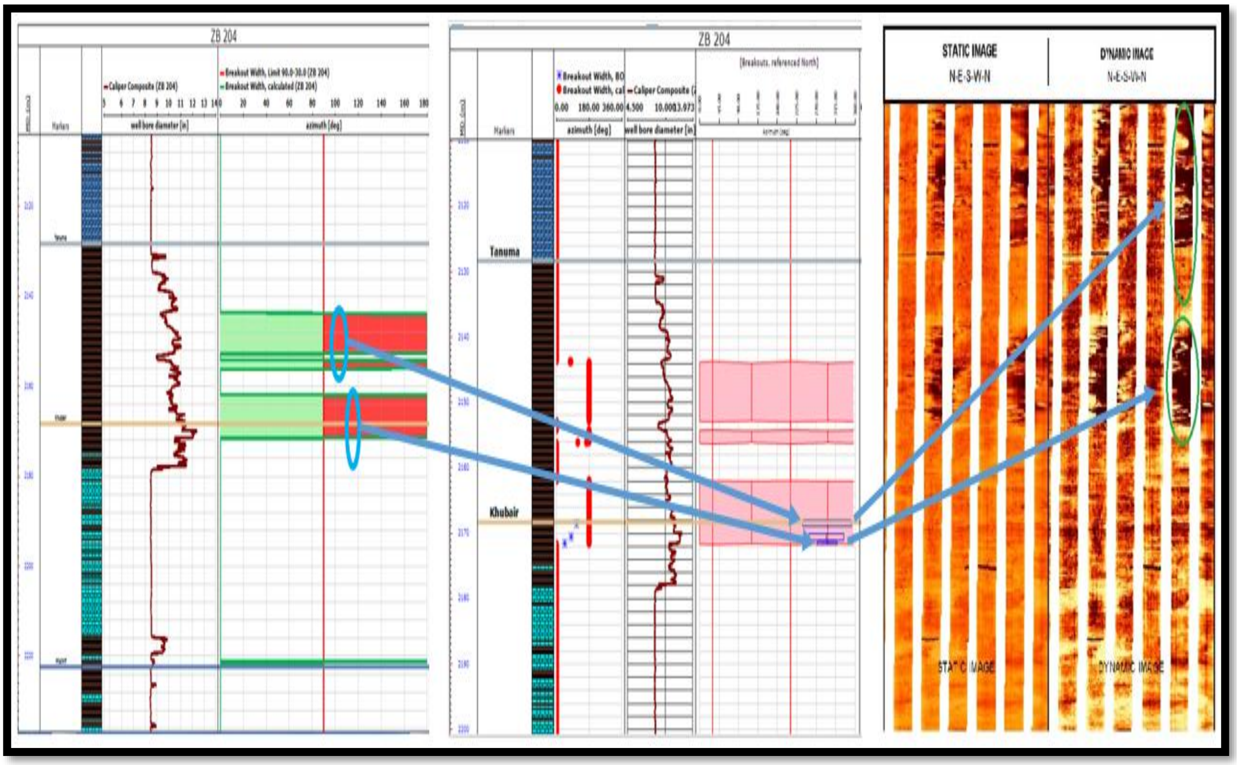

Figure 4. Breakout prediction and calibration (**Figures 1**,**2** and **3** gathered).

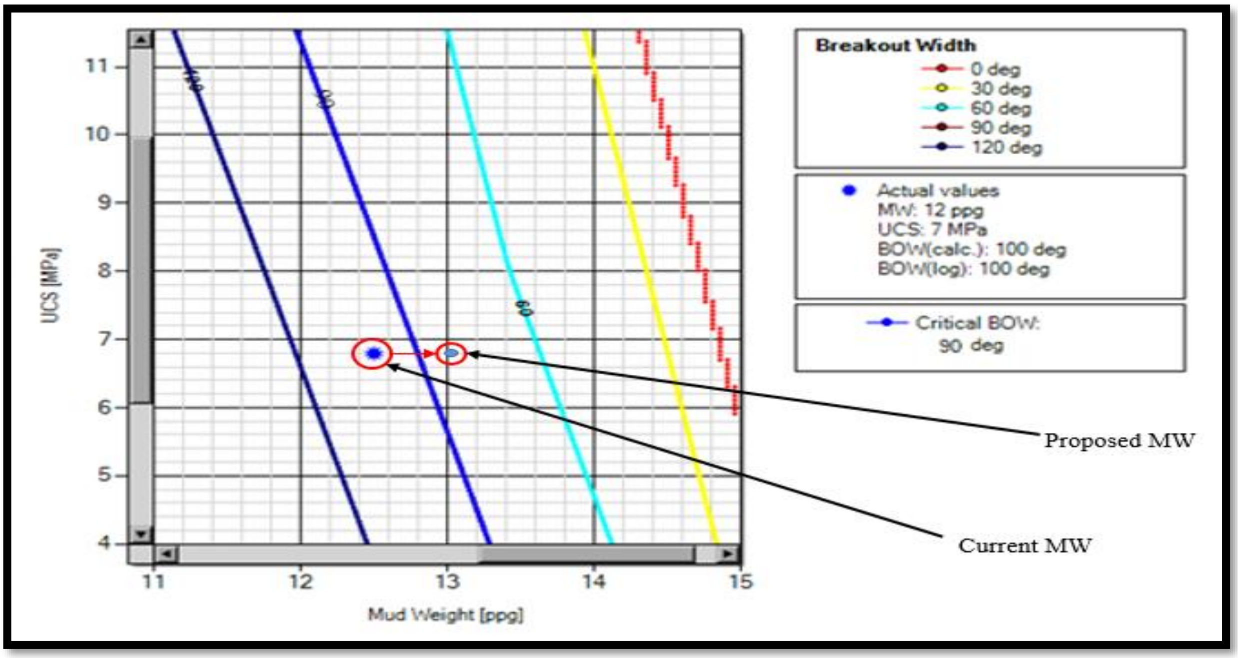

Figure 5. Breakouts as a function of Mud Weight and UCS.

It is necessary to investigate the importance of drilling direction on wellbore stability using the lower hemisphere plot for the three failure criteria using Baker Hughes's Jewelsuite Geomechanics 2018 software **(Fig. 6-a, 6-b and 6-c).** These figures show a modeled breakout width at the same depth of 2168 m. Colors indicate the breakout width (large breakouts are in red and small breakouts are in blue), circle circumference is the well azimuth and the three concentric circles are the well inclination (0 -90) degrees and the white small circle is the well understudy at zero degree (vertical).

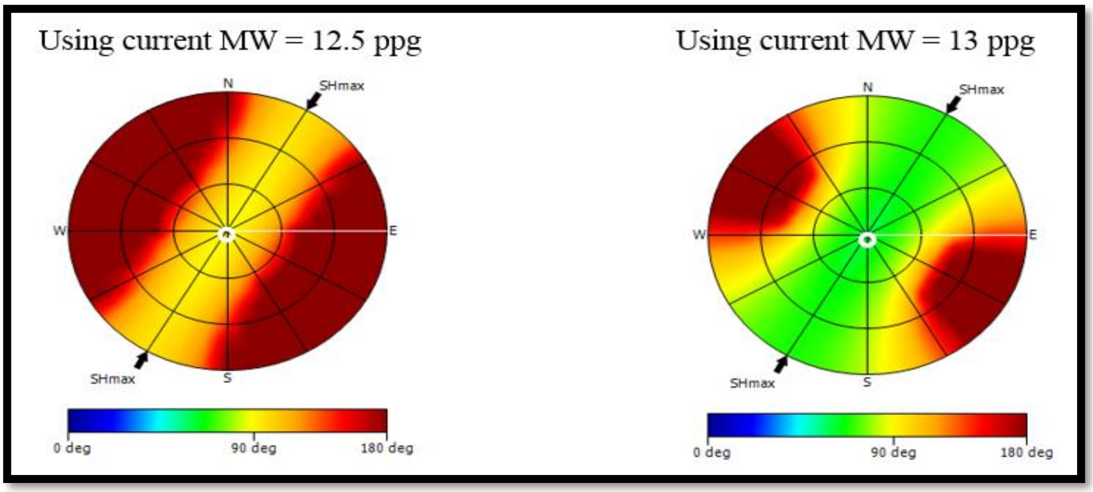

Figure 6-a. Effect of direction of drilling on the breakout width, Mohr-Coulomb failure criteria.

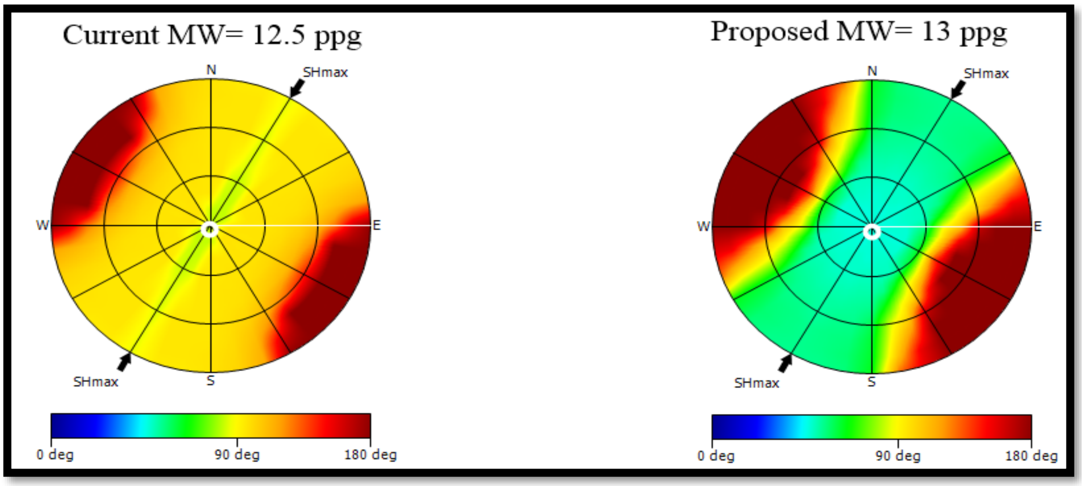

Figure 6-b. Effect of direction of drilling on the breakout width, Modified Lade failure criteria.

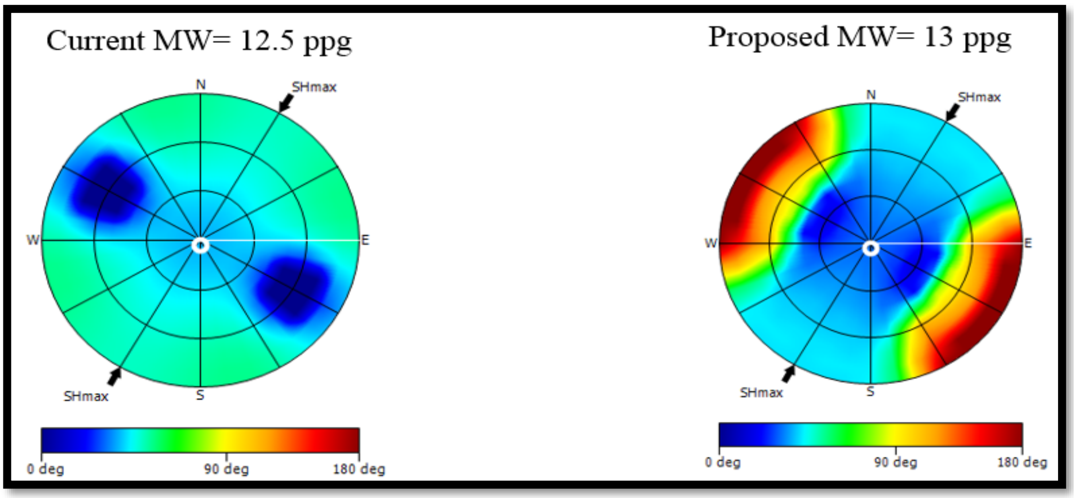

Figure 6-c. Effect of direction of drilling on the breakout width, Mogi-Coulomb failure criteria.

Results **(Fig. 6-a, 6-b and 6-c)** of using different failure criteria at depth of 2168m, shows that Mohr-Coulomb gives very good results that match with image logs and the modeled breakout width.

The lower limit of the mud window considered to be the maximum of pore pressure and collapse pressure while the upper limit is the fracture pressure gradient.

The pore pressure predicted using acoustic Eaton model (Eq. 1) using Baker Hughes's Jewelsuite Geomechanics 2018 software .

$$Pp = S - \left[(S - P_{NCT})\left(\frac{X_{NCT}}{X_{obs}}\right)^3\right] \quad (1)$$

Where,
Pp is the pore pressure, psi.

S is the overburden stress, psi.
P_{NCT} is the hydrostatic pressure value, psi.
Xnct, Xobs are the sonic log reading on the normal compaction trend line and on the log curve respectively, sec/ft.

The overburden stress calculated by integrating the available bulk density log using (Eq.2) using Baker Hughes's Jewelsuite Geomechanics 2018 software.

$$\sigma v = \int_0^Z \rho(z) * g * dz \tag{2}$$

where,
σv is the overburden stress, (Pa).
$\rho(z)$, is the bulk density log at depth z, (kg/m^3).
(g), is the constant of gravitational acceleration = 9.81 (m/s^2).
Z is the depth at the depth of interest, (m).

The fracture pressure calculated using Hubert and Willis Formula (Eq. 3) using Baker Hughes's Jewelsuite Geomechanics 2018 software.

$$P_F = Pp + 0.5(S + P_p) \tag{3}$$

where,

P_F is the Fracture Pressure.

Depending on the results of the pore pressure and the fracture gradient, the mud window model established for well ZB-204. This model shows a zone with abnormally high pore pressure with a narrow mud window from 2125m to 2200m, which is the Tanuma shaly formation.

The current mud weight program used in well ZB 204 is not suitable with the modeled mud window **(Fig.7-a)**, therefore, an alternative mud weight program suggested to safely drilling the overpressured zone.

Due to the narrow mud window predicted in Tanuma formation, an alternative casing design using Baker Hughes's Jewelsuite Geomechanics 2018 software, suggested to replace the current casing program and to seal the overpressured zone **(Fig.7-b)**.

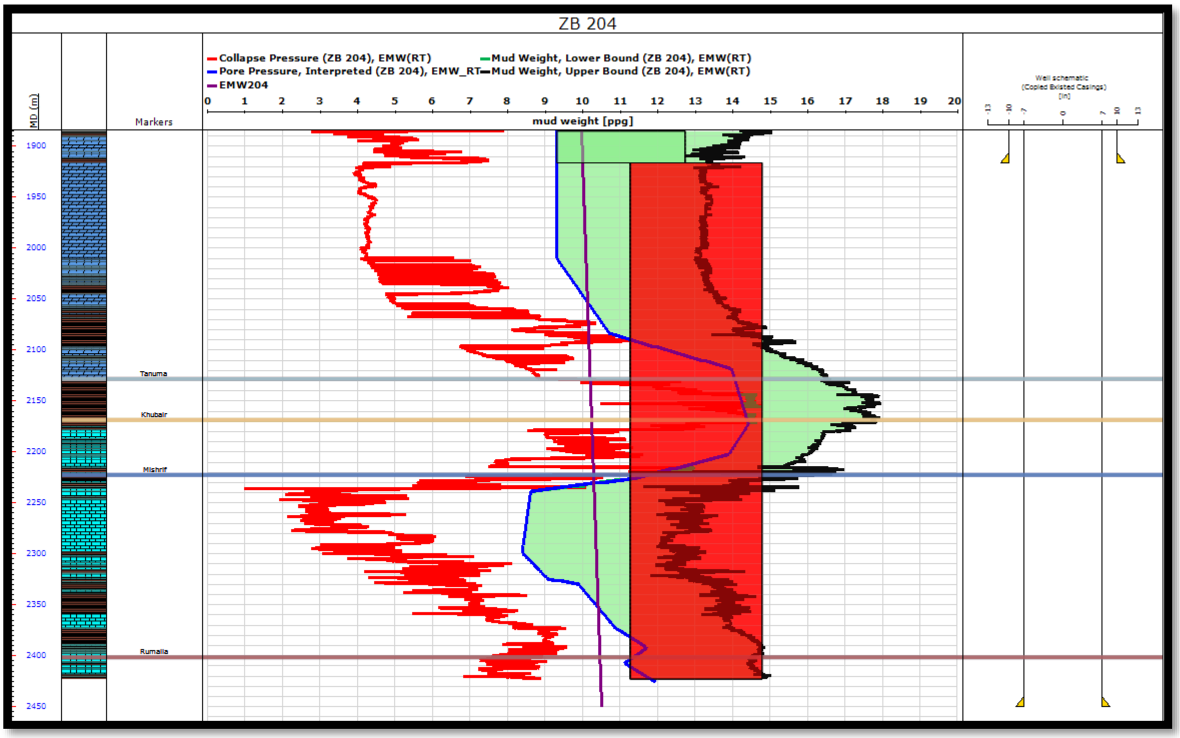

Figure 7-a. Previous mud weight and casing programs.

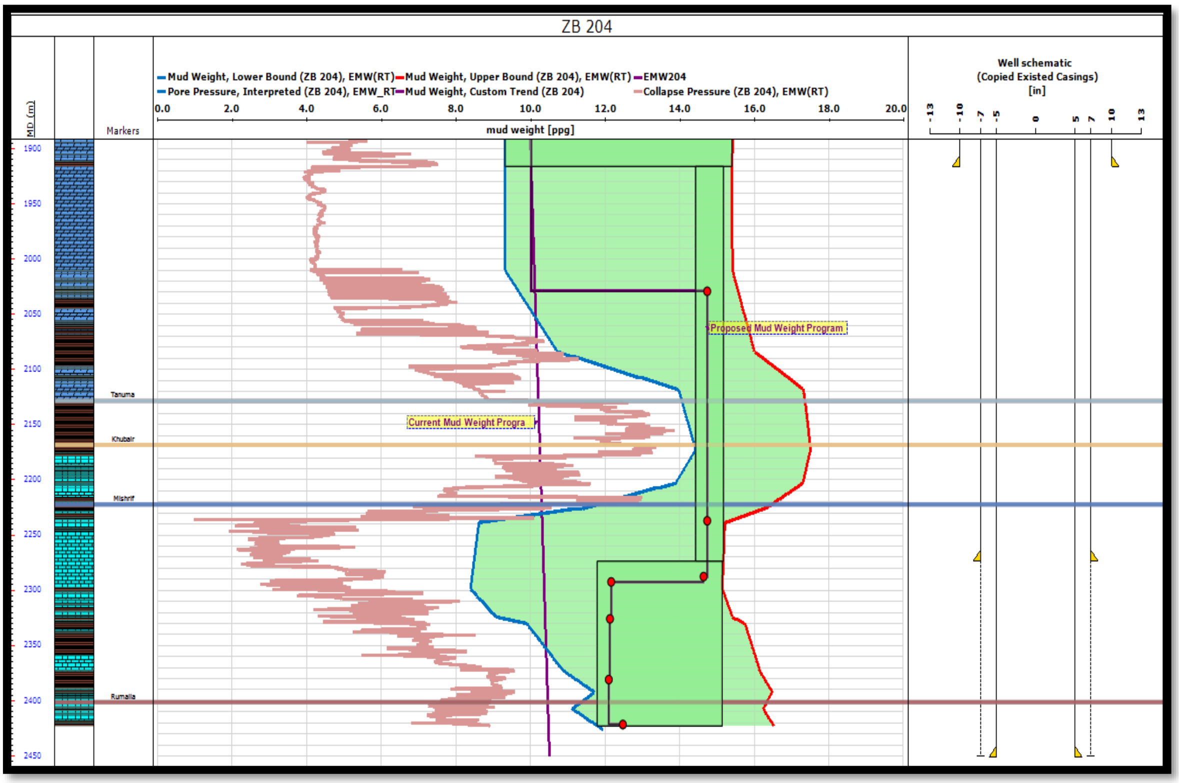

Figure 7-b. Suggested mud weight and casing programs.

3. CONCLUSIONS

1. Mohr-Coulomb is considered the best candidate for vertical wellbores especially in Zubair oilfield since it gave an excellent match with wellbore images (XRMI).
2. The new mud weight window model is not suitable with the current casing design, therefore; a new casing design is suggested by adding a new section to isolate the narrow mud window with overpressure.
3. Tanuma shale formation is a problematic formation type due to the over critical limits of the breakouts occurrence.
4. The transition zone of an increase in pore pressure is considered from 2075m to 2125m. Zone of over pressure is noticed from 2125m to 2200m in Tanuma shaly formation, which known as over pressure formation in southern Iraqi oilfields. Pore pressure returns to the value close to hydrostatic pressure in a gradual manner from 2200m to 2225m.

5. Recommendations

1. Due to the narrow mud window, over pressure formation (Tanuma formation), and the current mud weight is insufficient for such situations, therefore, it is advisable to study the applicability of the managed pressure drilling (MPD) technique to achieve the assumed drilling program and in situations similar to the model. Some previous studies utilized the MPD on nearby fields were mentioned in this study.
2. The newly suggested casing program consists of three sections instead of the previous two sections. The first section (10 inch) remains the same and extended from the surface to 1900m. The second section (7 inch) lowered to 2270m thereby isolating the troublesome zone. The third and final section (5 inch) will extend to the total depth (TD).

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