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Evaluation of Vertical Stress in Southern Iraq: A Comprehensive Analysis Using Well Log Data and Software Modification

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ABSTRACT

Vertical stress evaluation is pivotal in the domains of well construction and sand production assessment. This research focuses on estimating vertical stress within the Nahr Umr, Shuaiba, and Zubair layers at depths of 2737.5, 2990.83, and 3083m, respectively, within the Rumaila oil field. Various methodologies, including extrapolation, Miller, Amoco, Wendt non-acoustic, Traugott, and averaging density methods using Techlog 2021, are employed to predict vertical stress.Significantly, the extrapolation method excels in shallow depth calculations, while the Miller method accurately represents actual density values at greater depths, particularly within the Nahr Umr, Shuaiba, and Zubair layers. Remarkably close alignment is observed between the vertical stress values obtained from the Miller and extrapolation methods. For example, at the specified depths, the Miller method yields stress values of 8980, 9373, and 9981 psi, closely resembling the extrapolation method's results of 8987, 9373, and 9987 psi. Alternative techniques, including the Amoco, Wendt non-acoustic, Traugott, and average density methods, yield comparable outcomes. These approaches rely solely on density records as inputs and provide consistent apparent density values from the surface to the intended depth.Incorporating these findings into geomechanical modeling enhances comprehension of rock behavior under varying loads, offering valuable insights for optimized well construction and sand production management strategies. This research underscores the critical importance of understanding vertical stress as a cornerstone in achieving these objectives.

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تقييم الإجهاد العمودي في جنوب العراق: تحليل شامل باستخدام بيانات سجل الآبار وتعديل البرمجي

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الملخص

يعد تقييم الإجهاد العمودي أمرًا محوريًا في مجالات بناء الآبار وتقييم إنتاج الرمال. يركز هذا البحث على تقدير الإجهاد العمودي ضمن طبقات نهر عمر والشعيبة والزبير على أعماق 2737.5 و2990.83 و3083م على التوالي ضمن حقل الرميلة النفطي. يتم استخدام منهجيات مختلفة، بما في ذلك الاستقراء، وMiller، وAmoco، وWendt غير الصوتية، وTraugott، وطرق متوسط الكثافة باستخدام Techlog 2021، للتنبؤ بالإجهاد الرأسي. ومن الجدير بالذكر أن طريقة الاستقراء تتفوق في حسابات الأعماق الضحلة، في حين أن طريقة ميلر تمثل بدقة قيم الكثافة الفعلية في أعماق أكبر، وخاصة ضمن طبقات نهر عمر والشعيبة والزبير. ويلاحظ محاذاة وثيقة بشكل ملحوظ بين قيم الضغط الرأسي التي تم الحصول عليها من طريقتي ميلر والاستقراء. على سبيل المثال، عند الأعماق المحددة، تنتج طريقة ميلر قيم ضغط تبلغ 8980 و9373 و9981 رطل لكل بوصة مربعة، مما يشبه إلى حد كبير نتائج طريقة الاستقراء البالغة 8987 و9373 و9987 رطل لكل بوصة مربعة. تؤدي التقنيات البديلة، بما في ذلك طرق Amoco وWendt غير الصوتية وTraugott ومتوسطة الكثافة، إلى نتائج قابلة للمقارنة. تعتمد هذه الأساليب فقط على سجلات الكثافة كمدخلات وتوفر قيم كثافة واضحة متسقة من السطح إلى العمق المقصود يؤدي دمج هذه النتائج في النمذجة الجيوميكانيكية إلى تعزيز فهم سلوك الصخور تحت أحمال مختلفة، مما يوفر رؤى قيمة لاستراتيجيات بناء الآبار وإدارة إنتاج الرمال. يؤكد هذا البحث على الأهمية الحاسمة لفهم الإجهاد العمودي باعتباره حجر الزاوية في تحقيق هذه الأهداف.

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Introduction

The stability of rocks holds paramount importance across various applications, necessitating a comprehensive understanding of their responses to diverse loads (Allawi and Mohammed, 2022). Geomechanical structures' construction involves three significant stress types: vertical stress (σv), maximum stress, and minimum stress. Particularly crucial, vertical stress facilitates pore pressure calculation, horizontal stress determination, and fault regime identification within the structures (Alhusseini and Hamed-Allah, 2023). Overburden stress, a form of vertical stress, arises from the weight of overlying formations and their contained fluids. Additionally, geological features like salt domes near rock formations can contribute to other vertical stress types (Aadnoy and Looyeh, 2019). Assuming an average sediment density ranging from 1.8 to 2.2 g/cm³, vertical stress typically increases with depth at a rate of around 20 MPa/km (or commonly 0.8 to 1.0 psi/ft) (Ashoori, Abdideh, and Hayavi, 2014). Estimating vertical stress is crucial since rocks experience three principal stresses underground, and vertical stress is one of them (Almalikee and Al-Najim, 2018). Anderson's work in 1951 emphasized that predicting vertical stress, along with the other two stresses, simplifies assessing fault regime types (Zoback, 2006). Anderson classified fault regimes into normal, strike-slip, and reverse faulting regimes based on tectonic activity and the magnitudes of the three in-situ stresses, with the interaction between vertical stress and two horizontal stresses playing a key role (Scholz, 2019). Utilizing the Techlog 2021 software, vertical stress calculation for the Rumaila oil field can be performed using various methods. This study's objective was to determine the most effective strategy for forecasting vertical stress in the Rumaila oil field, employing different approaches. Furthermore, the study aimed to evaluate and compare the performance of the various employed methods.The aim of this study is to investigate the geological and reservoir characteristics of the Rumaila oilfield, situated approximately fifty kilometers northeast of the North Luhais oilfield in the southern city of Basrah, Iraq. The Rumaila oilfield extends between longitudes 30° 13' – 30° 24' and latitudes 47° 14' – 47° 19' (Al-Jaberi and Al-Mayyahi, 2018). Covering an area of 1800 square kilometers and located around fifty kilometers west of Basra city (Al-Mansory and Alrazzaq, 2021), the Rumaila oilfield is the largest in Iraq and was discovered in 1953. Production commenced in 1972, and it ranks sixth globally in terms of oil reserves, estimated to be around 17 billion barrels (Shaker, 2020). This study specifically focuses on the Rumaila North oilfield, which comprises two primary producing reservoirs, the Lower Cretaceous (Hauterivian-Aptian) Zubair Formation and the Upper Cretaceous (Cenomanian-Turonian) Shallow Marine Carbonate Mishrif Formation. The Zubair Formation stands as a highly prolific petroleum system within the southern region of Iraq (Abbas, Manhalawi, Alameedy, and Flori, 2019). These reservoirs are of significant interest due to their untapped resources and potential for increased production. The research aims to gain detailed insights into the geology, reservoir properties, and productivity potential of the Zubair and Mishrif formations within the Rumaila North oilfield (Al-Aradi, Alnajm, and Al-Khafaji, 2022). The dataset encompasses information from a single well within the Rumaila field, spanning across various layers. This dataset is composed of several types of data, specifically resistivity, density, gamma-ray (GR) readings, caliper measurements, and acoustic logs. The information provided in this dataset is corrected and refined for accuracy.

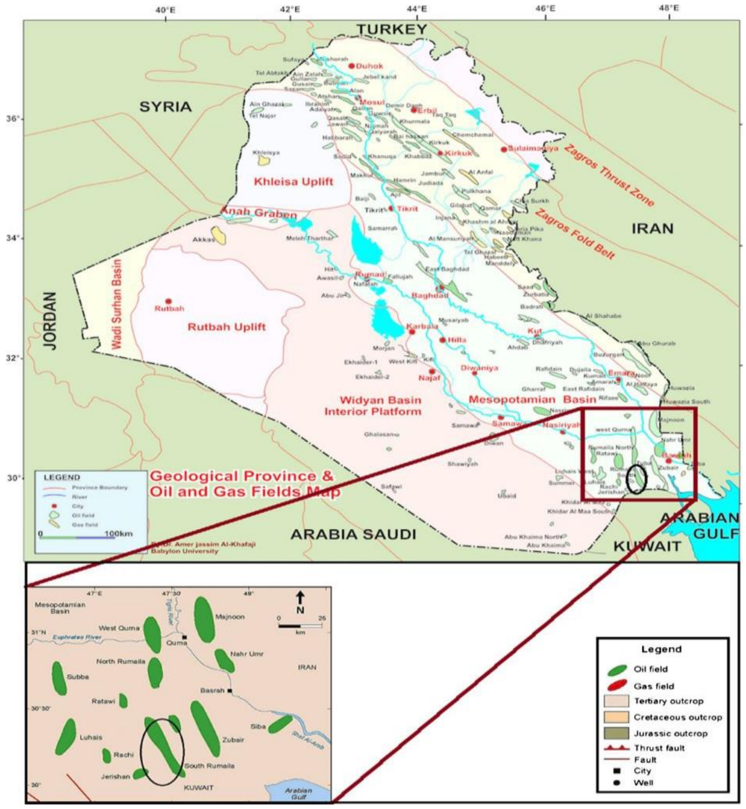

Fig. 1. Location map of the Rumaila Oilfield after (Al-Mudhafar, 2017)

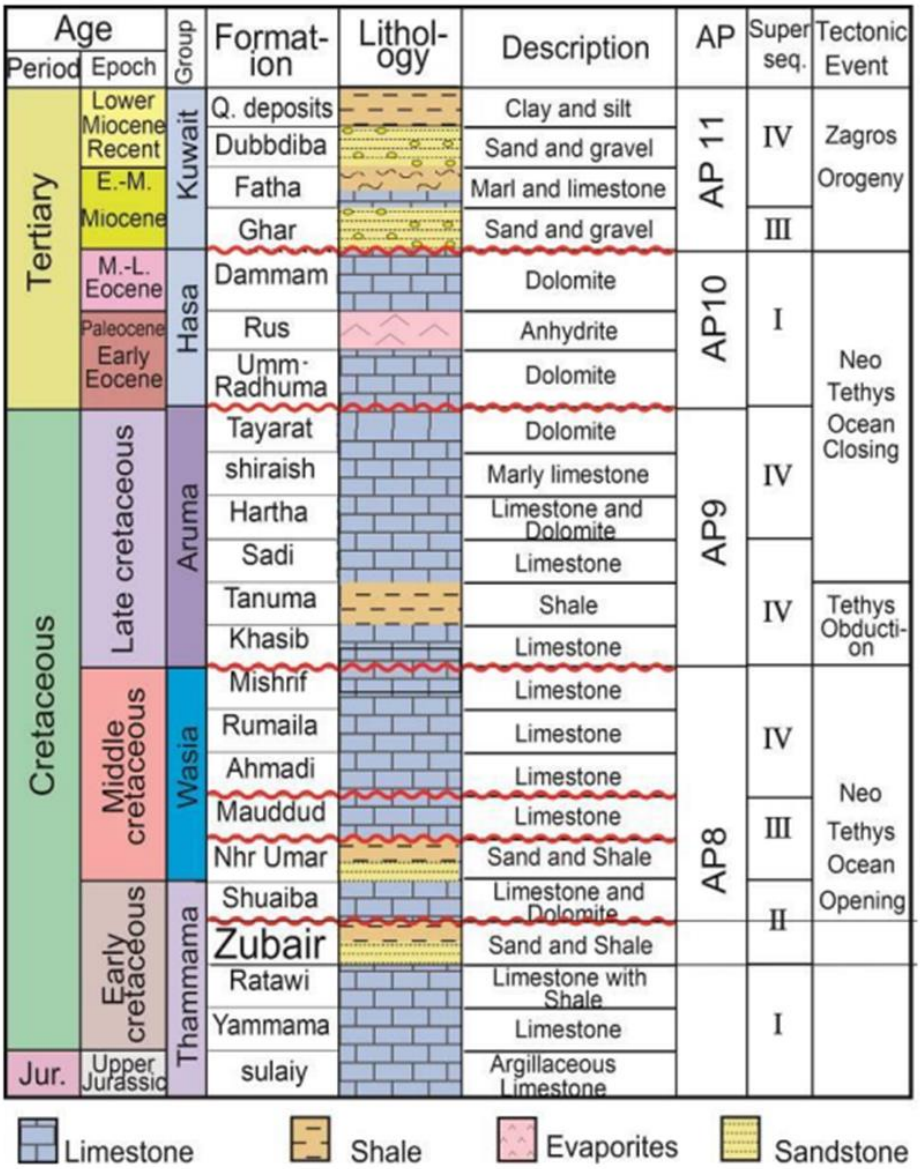

Fig.2.Stratigraphic map for North Rumaila oilfield (Al-Aradi, Alnajm, and Al-Khafaji, 2022).

Methodology

The diversity of required data emerged as a common challenge encountered during the computation of vertical stress. Estimating these variables demanded significant financial and time resources, contributing to the complexity of the task. For this study, data were collected from a specific well in the Rumaila oilfield, referred to as Ru. The analysis considered drilled wells that penetrated nine different levels: Tanumah, Khasib, Mishrif, Ramallah, Al-Ahmadi, Mauddud, Nhr Umr, Shuaiba and Zubair (Lazim, 2022). The data utilized in this study were obtained from various logs, including shear and compression Acoustic log, caliper logs, density logs, and gamma-ray logs. These logs provided valuable information for analysis, as depicted in Figure 3.

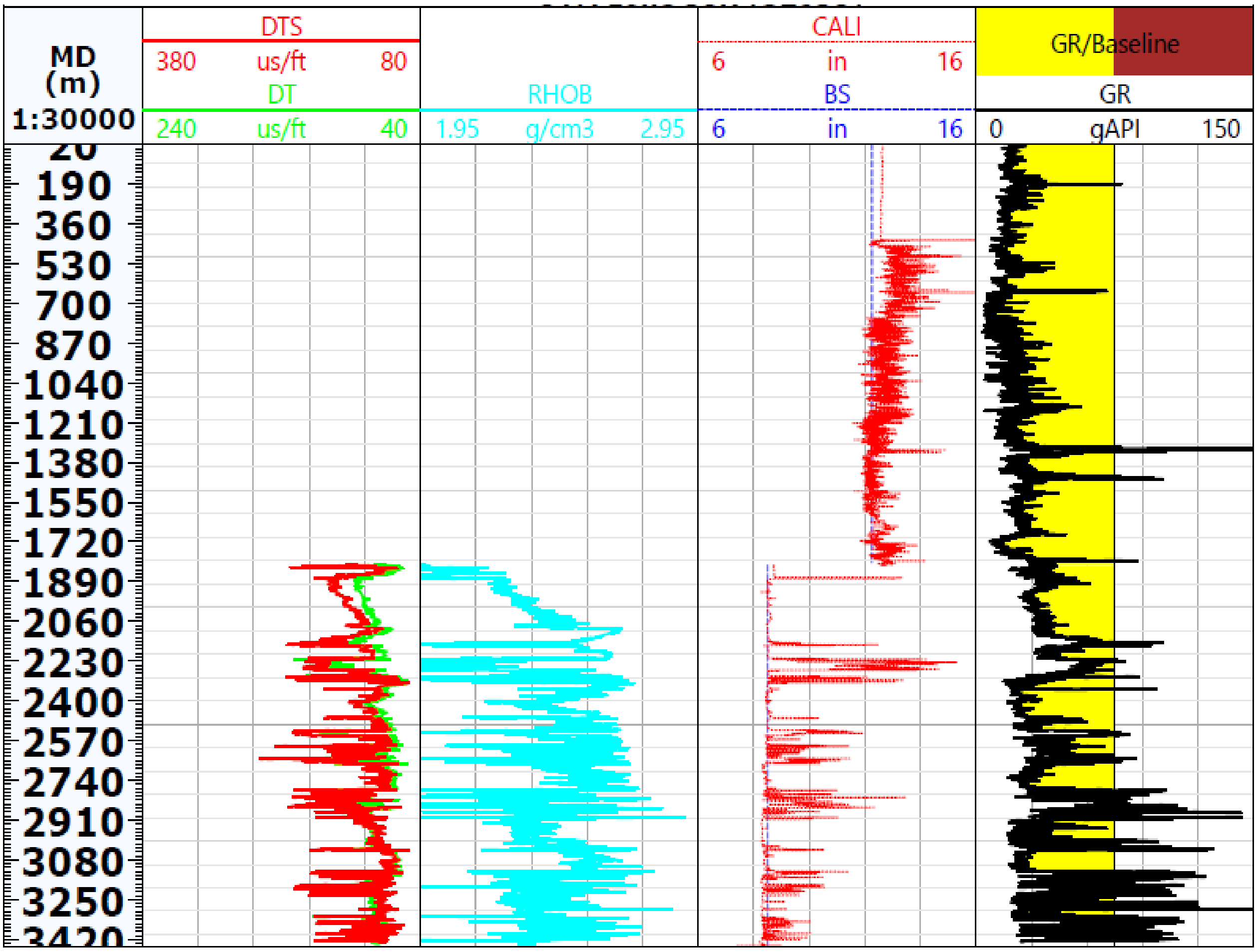

Fig. 3. The Rumaila oil field's Ru-X well provided the data for this investigation.

Vertical Stress (σv)

The magnitude of force applied to the rock at any specific depth. Represented as σv, can be calculated using Equation (1)

$$\sigma v = \int_0^z \rho(z) g \, dz \qquad (1)$$

Where:

σv: represents the vertical stress in psi

ρ: denotes bulk density in g/cm³

g: is the acceleration due to gravity.

Bulk density calculations often rely on logging tools and can be performed using various methods, as discussed by Bell in 2003. The density at a specific location incorporates the porosity, fluid density, and matrix density of the formation. For offshore wells, Equation 2 must be used to incorporate the depth and density of the water:

$$\sigma v = \rho w * g * Zw + \int \rho b * g * dz \qquad (2)$$

where:
ρb(z): Bulk density of the formation at depth (z)
ρw: Density of sea water
Zw: Water depth (Abbas, Flori, and Alsaba, 2019).

Extrapolated Density Method

The density needs to be extrapolated up to the mud line, a geometric fit can be employed using the following method. By providing density values at the mud line and two distinct depths (A and B) that are spaced apart, it is possible to determine the parameters required for the fit. These two depths are referred to as little depth (A) and Deep depth (B) as illustrated in Figure 4.

$$\rho\ extrapolated = \rho\ mudline + Ao \times (TVD - Air\ gap - Water\ Depth)\ a \qquad (3)$$

Where:

$\rho_{mudline}$: the density at the sea floor or ground level.

a: are the fitting parameters.

The interactive features allow users to modify the positions of points A and B on both the depth and density axes. Additionally, the mud line density can be adjusted by horizontally shifting the ML point. Furthermore, users have the flexibility to change the values for points A and B in the AWI (Alpha-Weighted Interpolation) by editing the parameters of Shallow depth, Deep depth, and their corresponding densities. The calculations are performed using the metric system, but Techlog automatically handles unit conversions when input is provided in either Metric or English units, as long as the units are specified. This paraphrased version accurately conveys the information regarding the interactive capabilities and unit handling in Techlog (Schlumberger Techlog 2021). The vertical stress of the Rumaila field was calculated by extrapolation, as shown in Figure 5.

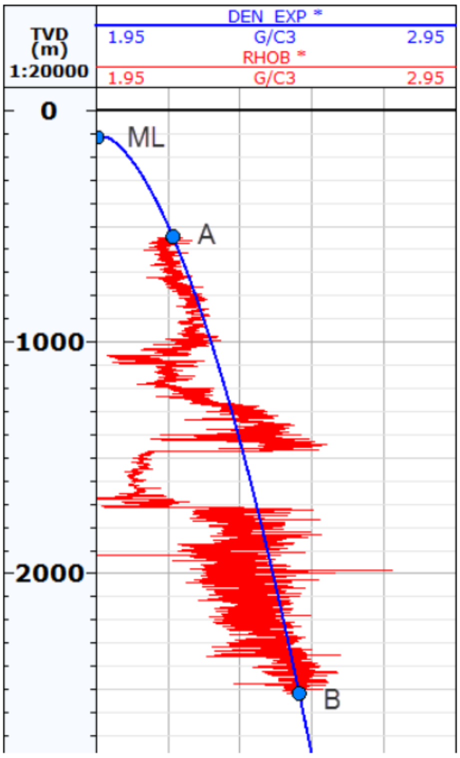

Fig. 4. An example of vertical stress calculation using the extrapolated density approach is presented in a publication by Schlumberger in 2021

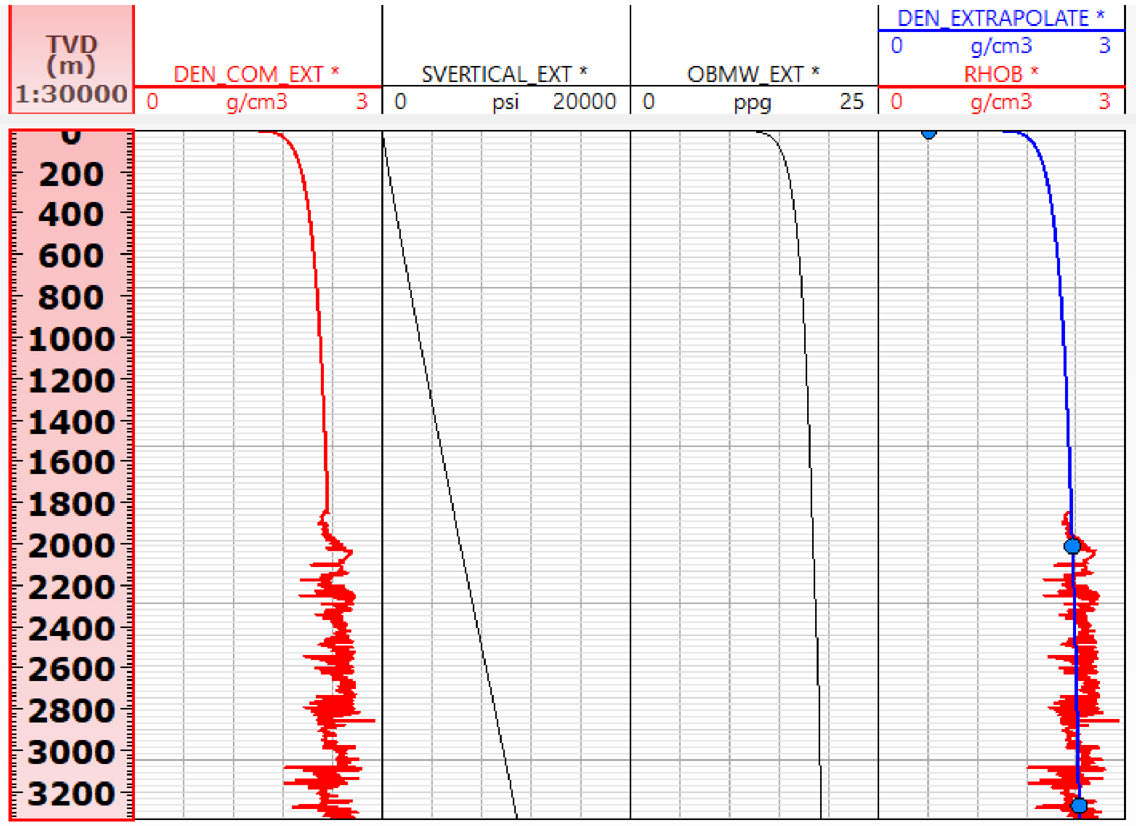

Fig. 5. The Extrapolated Density Method is employed to calculate vertical stress in geotechnical engineering.

Miller Density Method

To achieve the optimal fit for the density data, adjustments can be made to the fitting parameters K and N during the computation of Miller density from the total sediment porosity (Faraj and Hussein, 2023). This approach, as described in Schlumberger's publication from 2021, allows for fine-tuning the fitting parameters to obtain the best match with the density data, as shown in Figure 6.

$$\rho Miller = \rho Matrix\ (1-\emptyset Miller) + \rho Water\ \emptyset Miller \qquad (4)$$

$$\emptyset miller = \emptyset a + \phi_b e^{(-k(TVD-Air\ Gap-water\ depth)^{\frac{1}{N}})} \qquad (5)$$

Where: All depths are in ft.

$\rho Miller$ (Bulk Density): Mass of sediment/rock per unit volume (g/cm³).

$\rho matrix$ (Matrix Density): Density of solid matrix (2.65 g/cm³).

$\rho Water$ (Pore Water Density): Density of pore water (1.09 g/cm³).

Øa (Sediment Porosity at Great Depth): Porosity at significant depths (0.35).

Øb (Mud Line Porosity): Porosity at mud line (0.35).

K (Porosity Decline Parameter): Parameter for porosity decline with depth (0.0035).

N (Curvature Parameter): Parameter describing porosity-depth curvature (1.09).

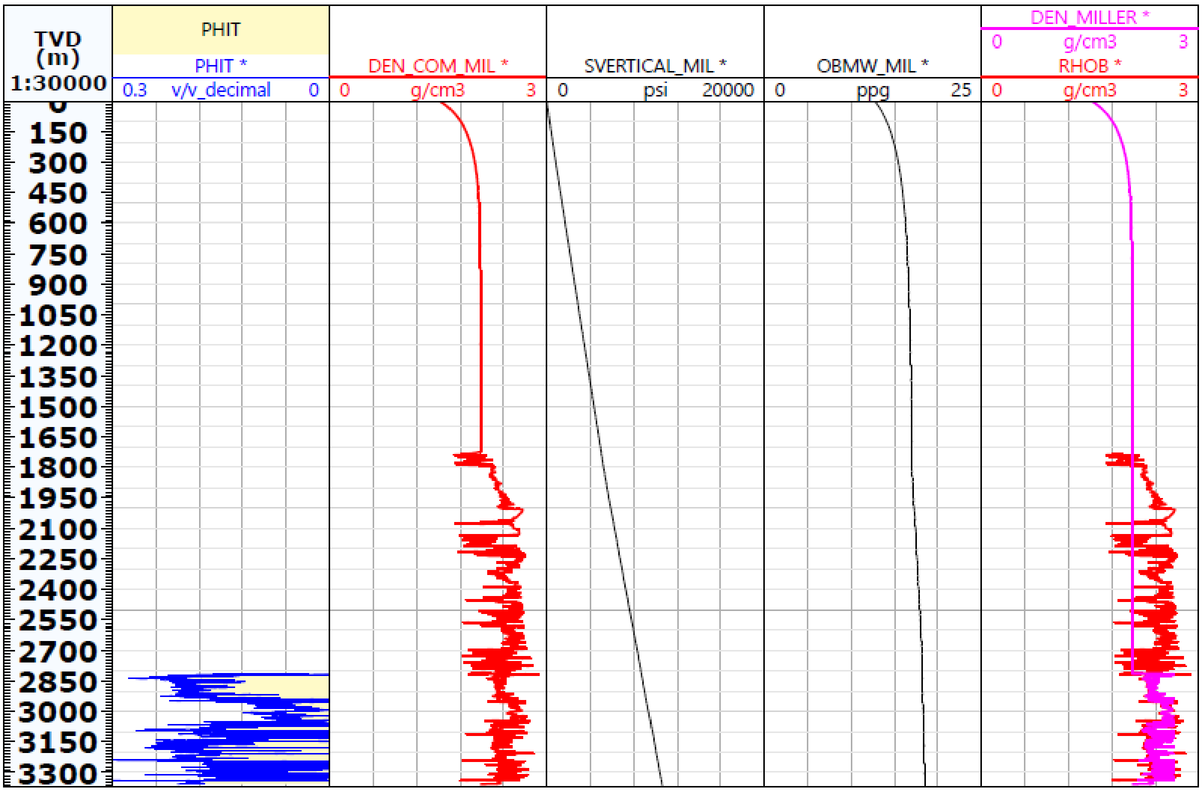

Fig. 6. Using the Miller Density approach, the vertical stress can be determined.

Amoco Empirical Relation

A mathematical formula based on statistical information gathered from the Gulf of Mexico needs to be developed, is employed to determine the average bulk density beneath the mudline. This equation ensures the best-fit density estimation (Schlumberger Techlog 2021). The vertical stress of the Rumaila field was calculated by Amoco, as shown in Figure 7.

$$\rho Amoco = \rho\ mudline + Ao \times [(TVD - Air\ gap - Water\ Depth)/3125]\ a \quad (6)$$

Where:

$\rho Amoco$: density in ppg.

ρ mudline: is mud density in ppg.

a: is the exponent coefficient (0.6) (Schlumberger Techlog 2021).

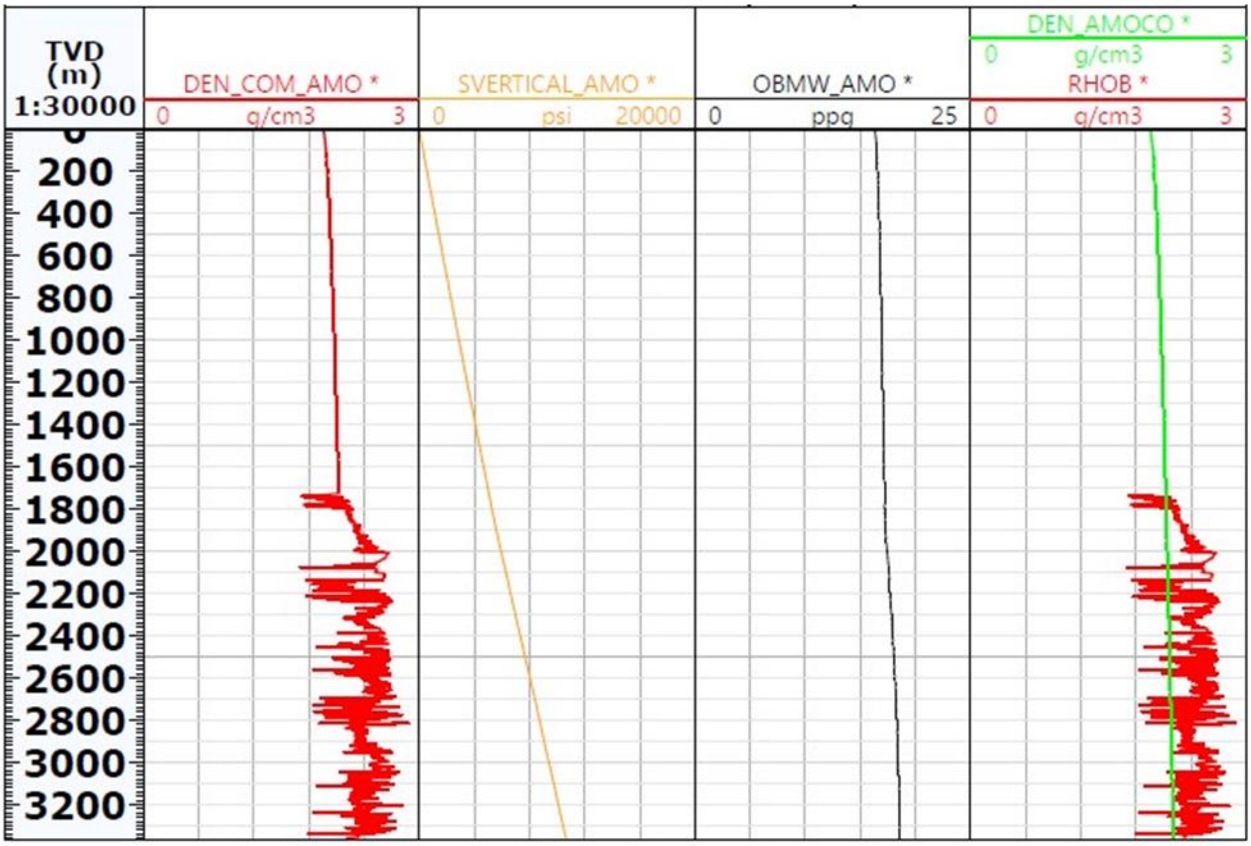

Fig. 7. Vertical stress by Amoco empirical relation

Wendt Non-Acoustic Method

The method described in Schlumberger's publication from 2021 determines density without relying on sonic data. It employs the following equation, which depicts density as a function of depth (Schlumberger Techlog 2021). equation 7 below allows for the calculation of density based on depth, providing an alternative approach when sonic data is unavailable. The vertical stress of the Rumaila field was calculated by Wendt non-acoustic, as shown in Figure 8.

$$\rho Wendt = DensityBias + DensityScalar \times WendtMultiplier \times (2.026 + 0.000025063 \times TVDMBL) \quad (7)$$

Where:

In the context of the provided information, the units for depth are in feet (ft) and the units for bulk density are in grams per cubic centimeter (g/cm³).

Additionally, the equation includes the following parameters:

Wendt Multiplier: This is a multiplier factor with a default value of 1.0.

Density Scalar: This represents the density scalar and has a default value of 1.0 g/cm³.

Density Bias: This parameter represents the density shift and has a default value of 0.0 g/cm³.

TVDBML: TVD (True Vertical Depth) below mudline, measured in feet (ft).

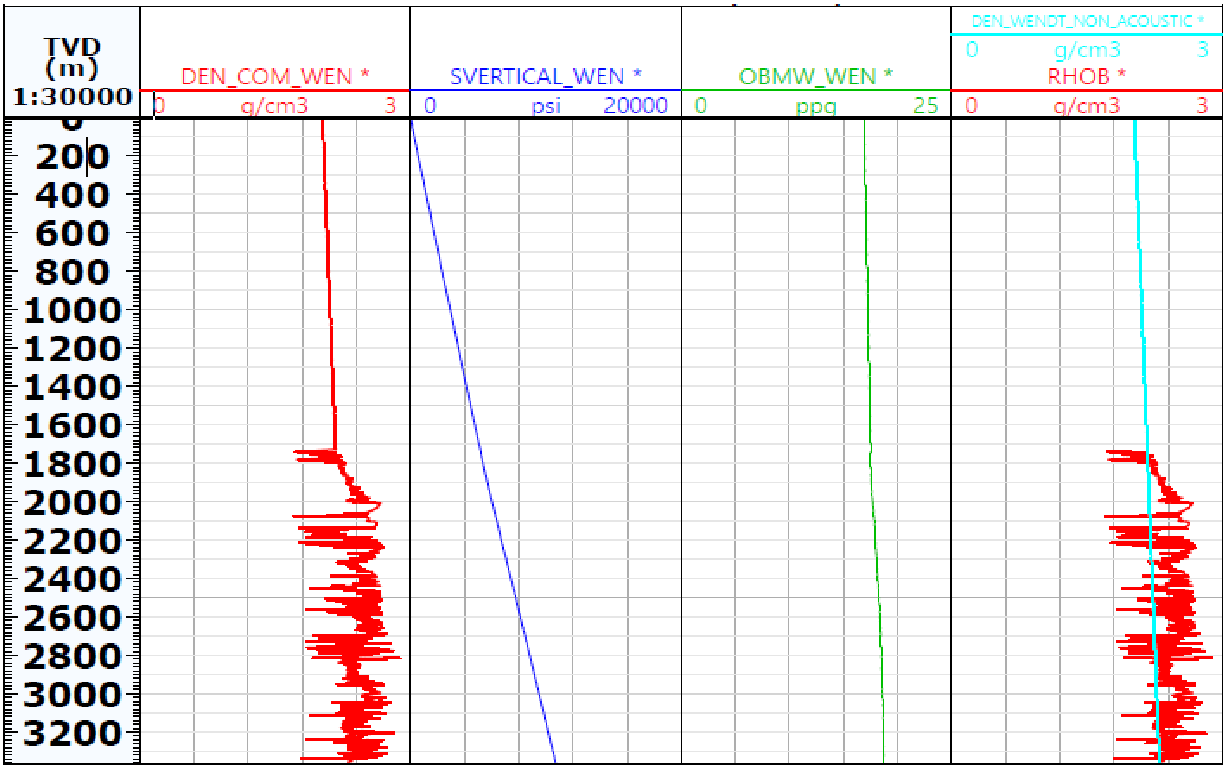

Fig. 8. Vertical stress by Wendt non-acoustic method

Traugott Density Method

Based on an exponential fit of the density data for Gulf Coast Miocene silt collected by Classen in 1966, David Scott and Martin Traugott developed an empirical model that accounts for diminishing porosity with depth. This empirical model was documented in reports by Amoco in 1988 and Traugott in 1997.

$$\sigma v=\frac{1}{2}(\sigma v+\rho b\times(Dnew-Dold)\ \times 0.43353+\sigma vtemp) \quad (8)$$

The uplift phenomenon is considered by applying a simple depth shift to the porosity curve. To estimate the horizontal stress component of the mean stress, the vertical effective stress assumes a normal pore pressure and makes a passive margin assumption. This estimation relies on determining the bulk density and integrating it to calculate the overburden. The process initiates at the mudline and progressively determines the density by considering the previously estimated overburden gradient. This paraphrased version accurately conveys the information regarding the consideration of uplift, vertical effective stress, and the process of determining density and overburden as shown in Figure 9 for the Rumaila field.

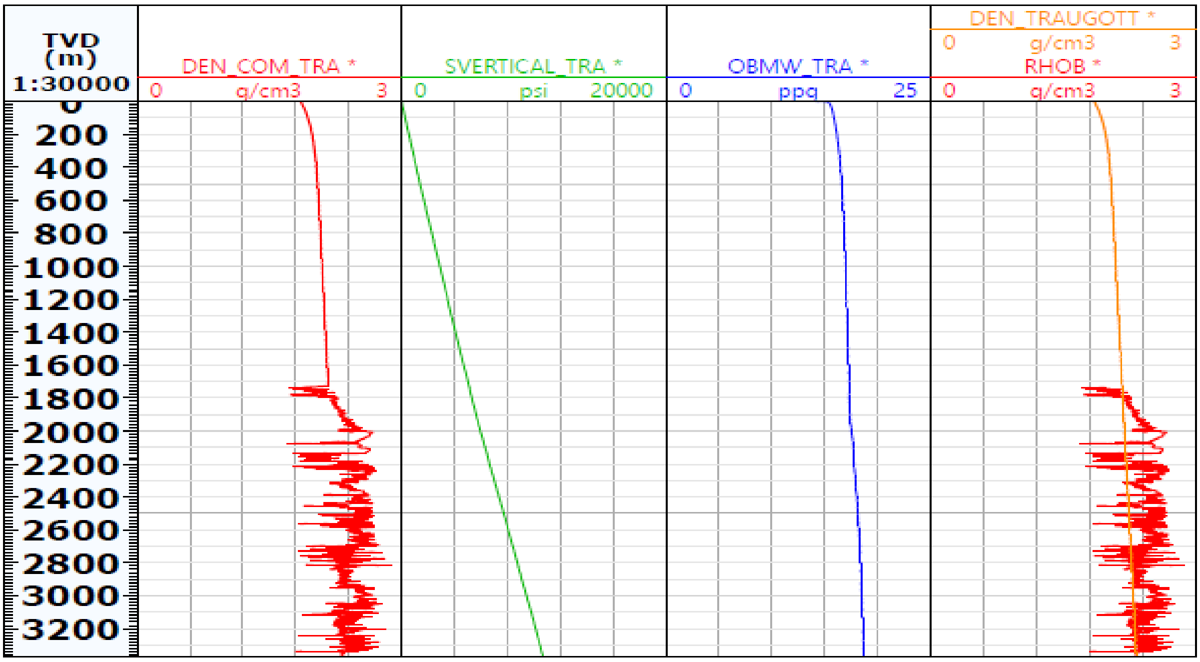

Fig. 9. Vertical stress by Traugott density method

Average Density Method

In this mode, Techlog can display both the depth and density curves with a fixed value. The average density is derived from the input density curve, and Techlog offers the flexibility to use different average densities based on zones. This information is provided in Schlumberger's publication from 2021, As shown in Figure 10 for the Rumaila field

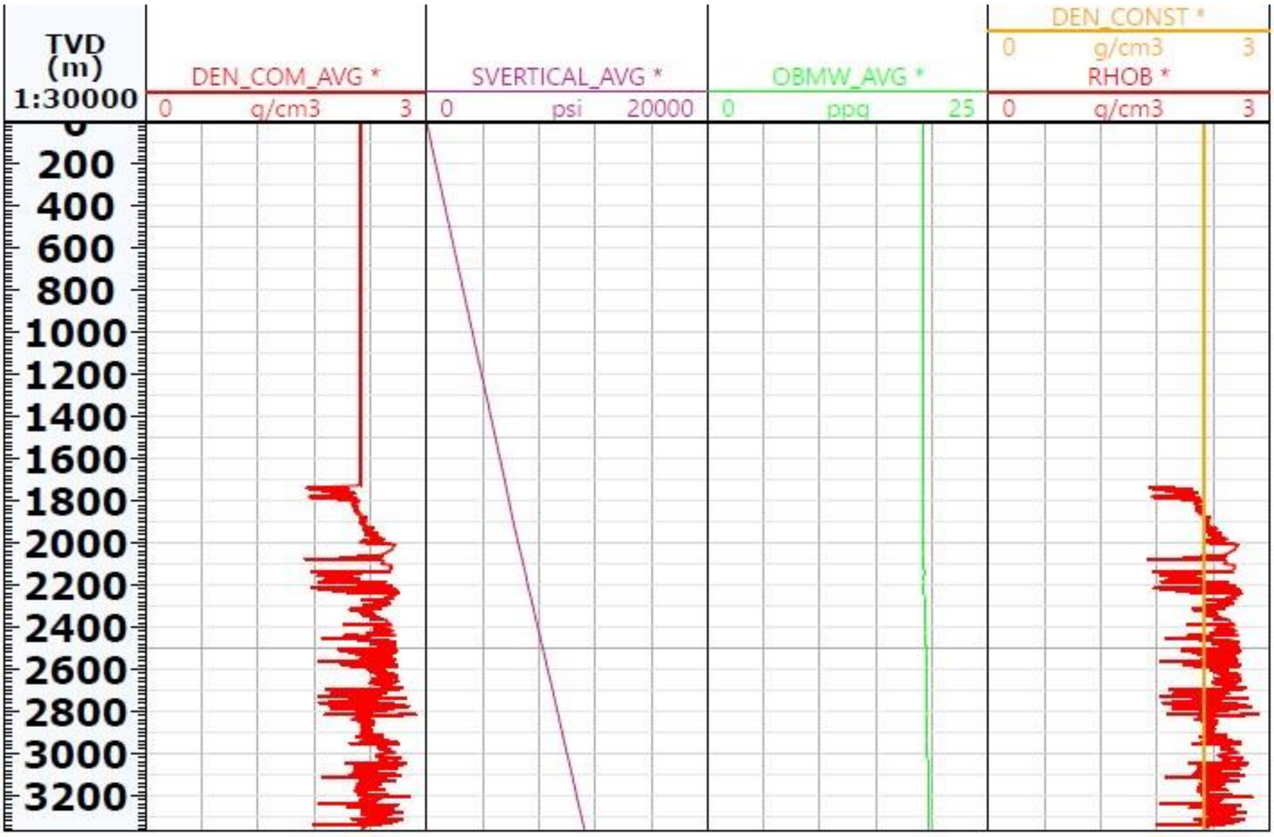

Fig. 10. Vertical stress by Average density method

Results and Discussion

The vertical stress is calculated using the extrapolated density method in the second track, SVERTICAL-EXT. The intensity calculation method in this approach is based on data from two selected sites, which are visually shown in Fig. 5. The intensity results obtained using this method are shown in the fifth lane, which is visually marked in blue. The extrapolated density measurement, utilizing an average gradient, provides accurate results for estimating vertical stress, particularly for shallow depths. Vertical stress is calculated using the Miller density method. The input data for this approach consisted of a total porosity record and a density record, as illustrated in Figure 6. Next, vertical stress was calculated in the fourth field and the line matched red with pink only at deeper depths. Different methods for calculating vertical stress are shown in Fig (7,8,9 and 10). Using the intensity log, all of these methods use a straight line as the observed intensity and use only the intensity log as an input. When choosing the best method for calculating vertical stress, it is important to consider the available data and the geological complexity of the study area. Table 1 displays different methods used to calculate the vertical stress in the Rumaila oil field. The data suggests that with increasing depth, the vertical pressure also increases. The extrapolation method proves to be the most accurate and reliable for shallow depths. On the other hand, the Miller method is better suited for greater depths, as evidenced by the results obtained for the layers Nhr Umr, Shuaiba, and Zubair. The values obtained through extrapolation for these layers are 8987, 9380, and 9987, while the Miller method yields values of 8980, 0373, and 9981, respectively. Experimental methods (Amoco, Wendt, Traugott, and average) are less accurate as they rely on assumptions of surface density.

Table. 1 Vertical stress range in psi units for each formation.

No.	Formation	Depth m	Extrapolate psi	Amoco psi	Miller psi	Wendt psi	Traugott psi	Average psi
1	Tanuma	2165	6821-7050	6463-6653	6631-6926	6595-6762	6565-6702	7100-7250
2	Khasib	2206	7050-7150	6653-6789	6926-7090	6762-6914	6702-6849	7250-7400
3	Mishrif	2271	7150-7545	6789-7045	7090-7512	6814-7129	6849-7119	7400-7680
4	Rumailla	2477	7545-8099	7045-7547	7512-7992	7129-7666	7119-7630	7680-8207
5	Ahmadi	2623	8099-8575	7547-8108	7992-8532	7666-8232	7630-8186	8207-8774
6	Mauddud	2737	8575-8987	8108-8545	8532-8980	8232-8643	8186-8535	8774-9120
7	Nhr Umr	2990	8987-9380	8545-9392	8980-9373	8643-9502	8535-9419	9120-9943
8	Shuaiba	3038	9380-9987	9392-9665	9373-9981	9502-9809	9419-9764	9943-10360
9	Zubair	3301	9987-10427	9665-10480	9981-10399	9809-10089	9764-9994	10360-10596

Conclusion

The precise estimation of vertical stress is crucial for various applications in the oil and gas industry, such as wellbore stability analysis and reservoir management. The extrapolated density method, which combines density measurements taken at different depths, can be used to achieve accurate results. However, for shallow formations, the Miller density approach may not accurately capture density variations, so alternative methods or additional data sources should be considered for improved accuracy. Empirical methods like Amoco, Wendt, and Traugott have shown consistent results and can be applied. Ultimately, the choice of the best method in Techlog depends on specific study requirements and available data. It is advisable to compare results from multiple methods and validate them against independent data sources or measurements for accuracy and reliability.

Nomenclature

Acronym	Definition	Unit
Ao	fitting parameter	dimensionless
BT	Bit size	in
D new	new depth	ft
D old	old depth	ft
DTCO	compressional sonic log	us/ft
DTSM	shear sonic log	us/ft
Zw	Water depth	ft

Ø*a*	Sedimentary porosity	p.u
Øb	Sedimentary porosity fitting parameter	p.u
g	gravity acceleration	m/s2
GR	gamma ray log	API
K	porosity decline parameter	dimensionless
N	curvature parameter	dimensionless
PHIT-ND	Total porosity	dimensionless
v *σ*	vertical stress	psi
β	fitting parameter	dimensionless
V	sonic velocity	ft/sec
TVD	true vertical depth	m
Ø miller	miller porosity	dimensionless
ρb	bulk density	g/cm3
ρw	Density of sea water	g/cm3
ρ mudline	Density at the sea floor or ground level	g/cm3
ρ matrix	matrix density	g/cm3
α	fitting parameter	dimensionless
a	Exponent coefficient	dimensionless
RHOZ	density log	g/cm3
SVERTICAL-EXT	Vertical stress by extrapolated	psi

References

Abbas, A.K., Flori, R.E. and Alsaba, M., 2019. Stability Analysis of Highly Deviated **B**oreholes to Minimize Drilling Risks and Nonproductive Time. Journal of Energy Resources Technology, 141(8), 082904. https://DOI.org/10.1115/1.4042733.

Abbas, A.K., Manhalawi, A., Alameedy, U. and Flori, R.E., 2019. Using an Analytical Model to Predict Collapse Volume During Drilling: A Case Study from Southern Iraq. In ARMA US Rock Mechanics/Geomechanics Symposium (pp. ARMA-2019). ARMA. https://DOI.org/10.1016/j.jafrearsci.2021.104165.

Aadnoy, B.S. and Looyeh, R., 2019. Petroleum Rock Mechanics: Drilling Operations and Well Design. Gulf professional publishing. https://DOI.org/10.2118/194578-MS.

Al-Aradi, H.T., Alnajm, F.M. and Al-Khafaji, A.J., 2022. Reservoir Properties of the Upper Sand Member of the Zubair Formation in North Rumaila Oil Field. The Iraqi Geological Journal, pp. 97-111. https://DOI.org/10.46717/igj.55.1C.8Ms-2022-03-27.

Alhusseini, A.K. and Hamed-Allah, S.M., 2023. Estimation Pore and Fracture Pressure Based on Log Data; Case Study: Mishrif Formation/Buzurgan Oilfield at Iraq. Iraqi Journal of Chemical and Petroleum Engineering, 24(1), pp. 65-78. https://DOI.org/10.31699/IJCPE.2023.1.8.

Al-Jaberi, M.H. and Al-Mayyahi, H.K., 2018. Wireline Logging Response and True Core Analysis of the Upper Shale Member of Zubair Formation, Rumaila Oilfield, Southern Iraq. The Iraqi Geological Journal, pp. 28-40. https://DOI.org/10.46717/igj.51.2.2Ms-2018-12-24.

Al-Malikee, H.S.A. and Al-Najim, F.M.S., 2018. Overburden Stress and Pore Pressure Prediction for the North Rumaila Oilfield, Iraq. Modeling Earth Systems and Environment, 4, pp. 1181-1188. https://DOI.org/10.1007/s40808-018-0475-4.

Al-Mansory, W. and Alrazzaq, A.A.A., 2021. Determination of Safe Mud Weight Window in Rumaila Oilfield, Southern Iraq. The Iraqi Geological Journal, pp. 48-61. https://DOI.org/10.46717/igj.54.2F.5ms-2021-12-22.

Al-Mudhafar, W.J., 2017. Geostatistical Lithofacies Modeling of the Upper Sandstone Member/Zubair Formation in South Rumaila Oilfield, Iraq. Arabian Journal of Geosciences, 10, pp. 1-14. https://DOI.org/10.1007/s12517-017-2951-y.

Ashoori, S., Abdideh, M. and Tabaeh Hayavi, M., 2014. Prediction of Critical Flow Rate for Preventing Sand Production Using the Mogi-Coulomb Failure Criterion. Science International, 26(5). http://www.sci-int.com/pdf/5590518521%20a--2029-2032-Ashoori-IRAN.pdf.

Faraj, A.K. and Hussein, H.A.A., 2023. Vertical Stress Prediction for Zubair Oil Field/Case Study. Journal of Engineering, 29(2), 137. https://DOI.org/10.31026/j.eng.2023.02.09.

Lazim, A.A., 2022. Structural Geology Study of Tuba Oilfield, Southern Iraq. The Iraqi Geological Journal, pp. 164-174. https://DOI.org/10.46717/igj.55.2C.12ms-2022-08-25.

Mohammed, Q.S., 2022. Dynamic Behavior of Machine Foundations on layered sandy soil under Seismic Loadings. Journal of Engineering, 28(8), pp. 1-20. https://DOI.org/10.31026/j.eng.2022.08.019.

Scholz, C.H., 2019. The Mechanics of Earthquakes and Faulting. Cambridge University Press. https://DOI.org/10.1063/5.0129689.

Shaker, N., Al-Mayyahi, H.K. and Al-Malikee, H.S., 2020. Variation of Saturation Pressure Values in Mishrif and Zubair Reservoirs in Rumaila Oilfield, Southern Iraq. The Iraqi Geological Journal, pp. 16-31. https://DOI.org/10.46717/igj.53.1E.2Ry-2020-07-02.

Zoback, M.D., 2006. Reservoir Geomechanics, Cambridge University Press, Cambridge, UK. https://DOI.org/10.1016/j.petrol.2006.01.003.