University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 29 Number 2 February 2023

Vertical Stress Prediction for Zubair Oil Field/ Case Study

Ali Khaleel Faraj *
MSc student
College of Engineering
University of Baghdad
Baghdad - Iraq
ali.faraj2008m@coeng.uobaghdad.edu.iq

Hassan A. Abdul Hussein
Asst. Prof. Dr.
College of Engineering
University of Baghdad
Baghdad - Iraq
Hahah692000@yahoo.com

ABSTRACT

Predicting vertical stress was indeed useful for controlling geomechanical issues since it allowed for the computation of pore pressure for the formation and classification of fault regimes. This study provides an in-depth observation of vertical stress prediction utilizing numerous approaches using the Techlog 2015 software. Gardner's method results in incorrect vertical stress values with a problem that this method doesn't start from the surface and instead relies only on sound log data. Whereas the Amoco, Wendt non-acoustic, Traugott, average technique simply needed density log as input and used a straight line as the observed density, this was incorrect for vertical computing stress. The results of these methods show that extrapolated density measurement used an average for the real density. The gradient of an extrapolated method is much better in shallow depth into the vertical stress calculations. The Miller density method had an excellent fit with the real density in deep depth. It has been crucial to calculate vertical stress for the past 40 years because calculating pore pressure and geomechanical building models have employed vertical stress as input. The strongest predictor of vertical stress may have been bulk density. According to these results, the miller and extrapolated techniques may be the best two methods for determining vertical stress. Still, the gradient of an extrapolated method is much more excellent in shallow depth than the miller method. Extrapolated density approach may produce satisfactory results for vertical stress, while miller values are lower than those obtained by extrapolating. This may be due to the poor gradient of this method at shallow depths. Gardner's approach incorrectly displays minimum values of about 4000 psi at great depths. While other methods provide numbers that are similar because these methods use constant bulk density values that start at the surface and continue to the desired depth, this is incorrect.

Keywords: Vertical stress, Miller Density, Extrapolated Method, Gardner Method, Amoco Correlation.

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2023.02.09

Article received: 21/7/2022
Article accepted: 11/9/2022
Article published: 1/2/2023

توقع الإجهاد العمودي لحقل الزبير النفطي / دراسة حالة

علي خليل فرج
طالب ماجستير
كلية الهندسة – جامعة بغداد
بغداد– العراق

حسن عبد الهادي عبد الحسن
أ.م. د
كلية الهندسة – جامعة بغداد
بغداد– العراق

الخلاصة

يعتبر توقع الإجهاد الرأسي مفيدًا بالفعل للتحكم في القضايا الجيوميكانيكية لأنه يسمح بحساب ضغط المسام لتشكيل وتصنيف أنظمة الفوالق والشقوق. في هذه الدراسة، نقدم مراقبة متعمقة حول التنبؤ بالإجهاد الرأسي باستخدام العديد من الطرق الموجودة في برنامج Techlog 2015.اظهرت النتائج أن طريقة قياس الكثافة المستقرة يستخدم متوسط الكثافة الحقيقية، حيث التدرج في حساب الكثافة في الأعماق الضحلة أفضل بكثيرفي حسابات الإجهاد العامودي بينما ينتج عن طريقة Gardner قيم ضغط عامودي غير صحيحة مع مشكلة أن هذه الطريقة لا تبدأ من السطح وبدلاً من ذلك يعتمد فقط على بيانات سجل الصوت. في حين أن تقنية Amoco وWendt non-acoustic و Traugott و average احتاجت ببساطة إلى سجل الكثافة كمدخل واستخدمت خط مستقيمًا ككثافة ملحوظة، كان هذا غير صحيح لحساب الإجهاد العمودي . طريقة كثافة ميلر وكان لها توافق ممتاز مع الكثافة الحقيقية عند الأعماق العميقة.

حساب الإجهاد الرأسي على مدار الأربعين عامًا الماضية جدا مهم، لأنه حساب ضغط المسام وبناء النماذج الجيوميكانيكية يعتبر الضغط الرأسي كمدخل لها. قد يكون أقوى مؤشر على الإجهاد العمودي هو الكثافة الظاهرية. قد تكون تقنيات الكثافة المستقرة وmiller أفضل طريقتين لتحديد الإجهاد الرأسي وفقًا لهذه النتائج ولكن التدرج للطريقة الكثافة المستقرة ممتازة كثيرًا في العمق الضحل من طريقة ميلر. قد ينتج عن طريقة الكثافة المستقرة نتائج مرضية للضغط العمودي بينما تكون قيم الإجهاد العمودي بواسطة ميلر أقل من تلك التي تم الحصول عليها عن طريق الكثافة المستقرة، وقد يكون هذا بسبب التدرج الضعيف لهذه الطريقة في الأعماق الضحلة. يعرض نهج جاردنر قيم قليلة لإجهاد العمودي بشكل غير صحيح حوالي 4000 رطل لكل بوصة مربعة على أعماق كبيرة. بينما توفر الطرق الأخرى أرقامًا متشابهة لأن هذه الطرق تستخدم قيمًا ثابتة للكثافة الظاهرية تبدأ من السطح وتستمر إلى العمق المطلوب، إلا أن هذا غير صحيح.

الكلمات الرئيسية: الإجهاد العامودي, كثافة ميلر, نهج جاردنر, طريقة كاردنر, تقنية اموكو

1. INTRODUCTION

Because rock stability is so crucial, how a rock responds to dynamic load differs from how it responds to static load, (Mohammed, 2022). In the construction of geomechanical structures, three stresses, vertical, maximum, and minimum, are extremely significant. Vertical stress is more effective since it may be utilized to compute pore pressure, horizontal stresses, and their connection to classify the faults regime of formations**.** Overburden Stress, also known as vertical stress Sv, is mostly brought on by the weight of the above formations and the fluids they hold. Some other types of vertical stress are brought on by geological phenomena like magma intrusion or salt domes in the vicinity of the rock formation **(Aadnoy and Looyeh, 2011).** The vertical tension changes linearly with depth when the layers are cemented and tightly compressed. The overburden gradient is 1 psi/ft, and the average sediment density is between 1.8 and 2.2 g/cm^3 **(Fjar et al., 2008).**

Estimating the vertical stress is very important because the rock is subjected to three principal stresses at any point underground. Vertical stress is one of these three stresses. Anderson suggested that it will be simpler to assess faults regimes types by predicting vertical stress and the other two stresses **(Zoback, 2010).** Depending on the tectonic activity and the amplitude of three in-situ stresses, Anderson in 1951, categorized fault regimes in a specific area based on the connection between the vertical stress and two horizontal stresses as being characterized by normal, strike-slip, and reverse faulting **(Scholz, 2019).** The most important factor affecting vertical stress was depth. When depth increased, the vertical stress increased **(Daham, 2021).** Another factor was the density of the rock, type of lithology, formation pressure, and effective stress **(Jaeger et al., 2009).**
One of Iraq's biggest oil fields is Zubair. It is located about 20 kilometers southwest of Basra, as shown in **Fig.1** below. This field was founded in 1949, and work on it began in 1951. The Zubair oilfield, which is a part of the quasiplatform foreland of the Arabian plate, is situated in the sagging pelvis of the Mesopotamian zone, according to the tectonic zones of Iraq **(Mohajjel et al., 2000)**. **Fig.2** below shows the geological column in this field and the import section for this study. Different approaches can be used to calculate vertical stress using Techlog 2015 software for the Zubair oil field. This study aimed to determine the optimal approach for predicting vertical stress in the carbonate reservoir for the Zubair oil field by calculating vertical stress using several methods. The other purpose of this study was to examine and compare the various methods.

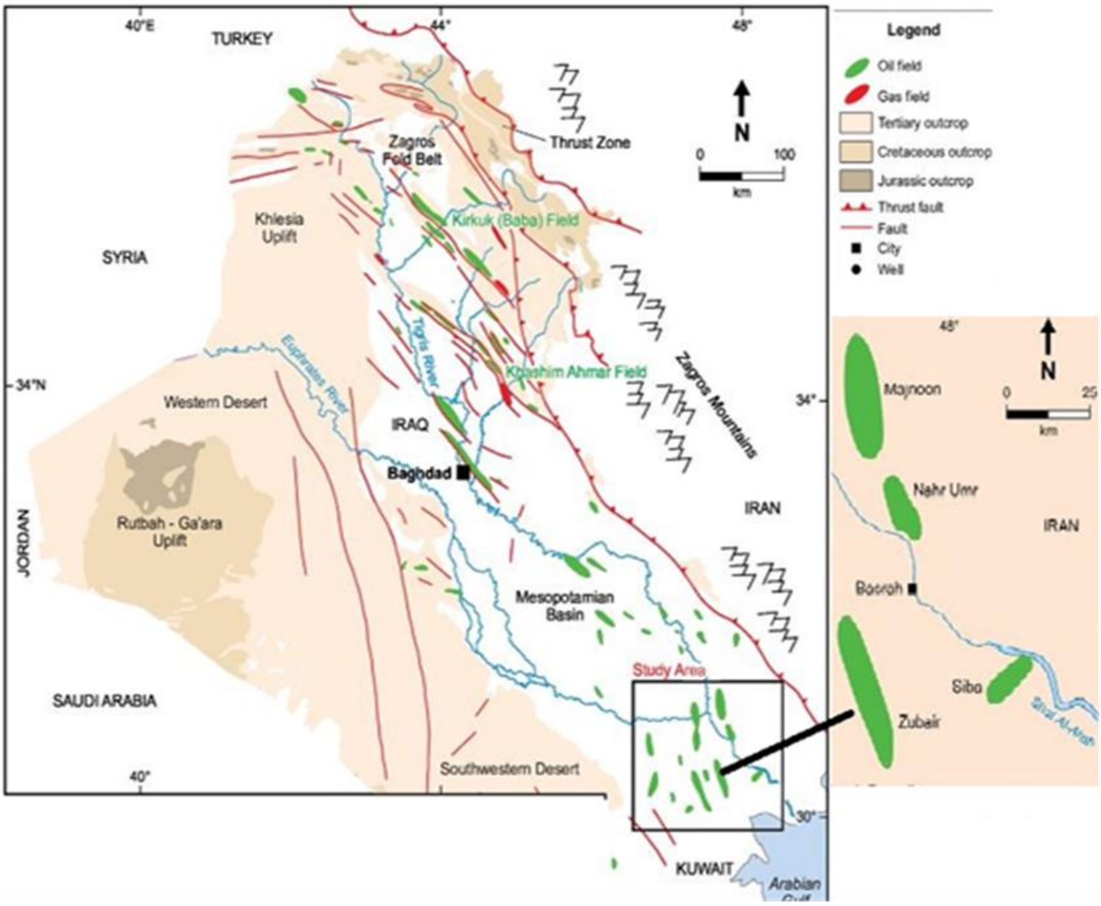

Figure 1. Location map of Zubair oil field **(Al-Ameri et al., 2009).**

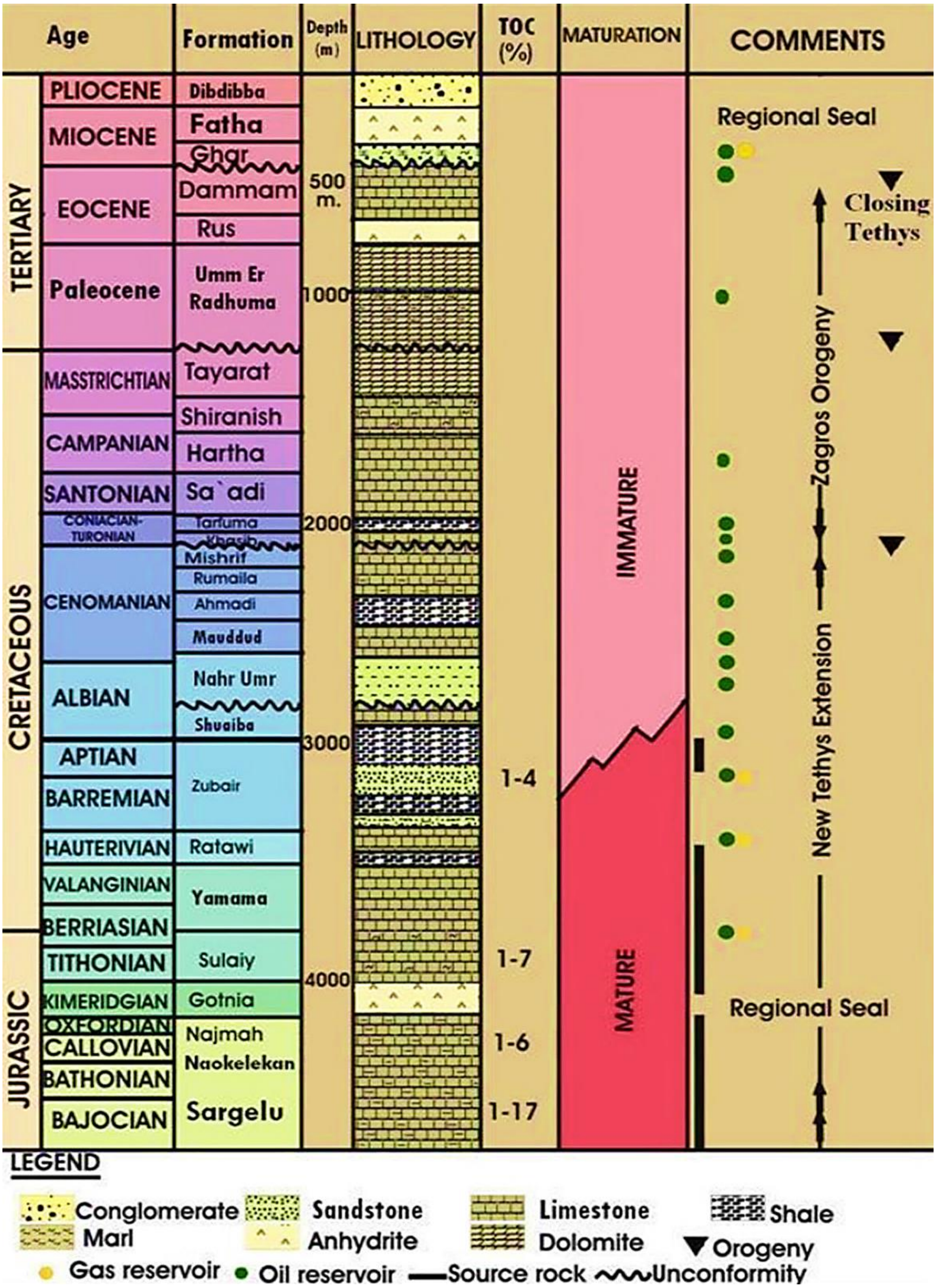

Figure 2. Geological Column of Zubair oil fields **(Al-Ameri et al., 2011).**

2. Methodology

The variety of necessary data was the most frequent problem faced while calculating the vertical stress due to the high cost and time for the estimation of these data. Data were obtained from the Zubair oil field's one well called ZA-2, which has two domes (Shuaiba and Al-Hamar). Section 12.25" was taken into consideration in the drilled wells, which penetrated six levels (Sadi, Tanuma, Khasib, Mishrif, Rumulla, and Ahmadi), as shown in **Table 1.** below. The information came from logs, for example, gamma-ray, caliper, density, and sound logs (shear and compression), as shown in **Fig. 3**.

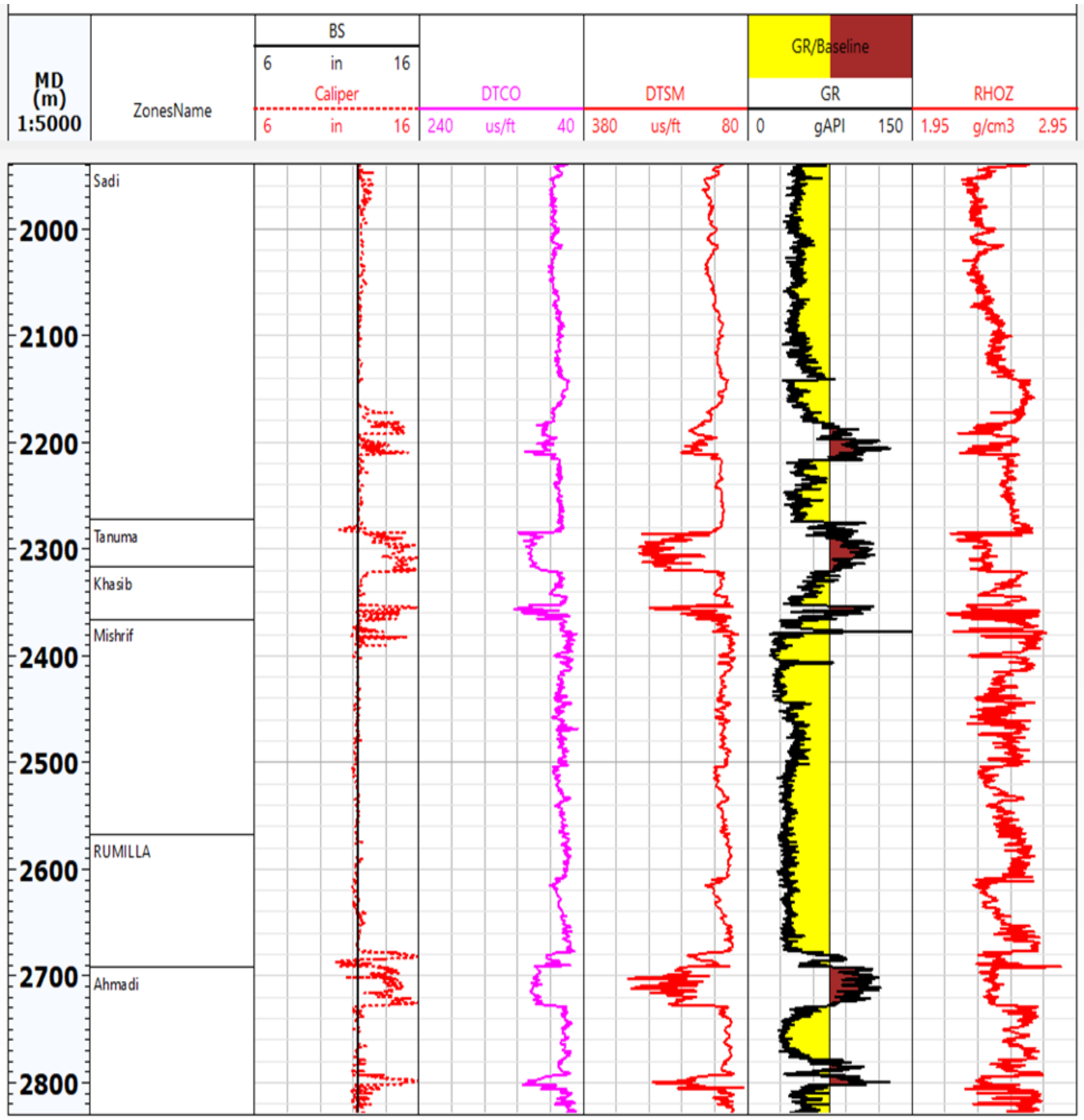

Figure 3. Data for this study were from the Zubair oil field for ZA-2 well.

Table 1. Available data with the formation and concerned depth for this study.

No	Well ZA-2		
	Available log	Formation	Depth (m)
1	Caliper	Sadi	1939
2	Gamm-ray	Tanuma	2272
3	Density	Khasib	2317
4	Compressional acoustic log	Mishrif	2366
5	Shear acoustic log	Rumailla	2568
6	Netron log	Ahmadi	2692

2.1. Vertical Stress (Sv)

Eq. (1) can be used to calculate the pressure exerted on the rock at any depth as a result of the weight of the rock and the fluid it contains.

$$Sv = \int_0^z \rho\ (z)\ \ g\ dz \tag{1}$$

Sv is the vertical stress in (psi), ρ bulk density in g/cm^3, and g is a gravity acceleration. There are different methods for calculating bulk density, and logging tools have been utilized extensively in this process **(Bell, 2003)**. Any given point's density is seen as a composite of the formation's porosity, fluid density, and matrix density.

2.1.1. Extrapolated density method

The following geometric fit can be used to extrapolate density up to the mud line since the mud line depth (ML) is known. For a total of five parameters, you can enter density values at the mud line and at two points (A and B) that are spaced apart in depth. These values are known as Shallow depth (A) and Deep depth (B), as shown in **Fig.4.** The positions of points A and B on the depth and density axes can be changed interactively **(Schlumberger, 2015).**

$$\rho\ extrapolated = \rho\ mudline\ + Ao \times (TVD - Air\ gap\ - Water\ Depth)^{\alpha} \tag{2}$$

where: ρ mudline is the density at the seafloor or ground level. Ao and α are the fitting parameters.

2.1.2 Miller density method

Miller density is computed from total sediment porosity, and by adjusting the fitting parameters K and N, this method can provide the best match for the density data **(Schlumberger, 2015).**

$$\rho_{Miller} = \rho_{Matrix}(1 - \emptyset_{Miller}) + \rho_{Water}\ \emptyset_{Miller} \tag{3}$$

$$\emptyset_{Miller} = \emptyset_a + \emptyset_b e^{\left[-k(TVD-AirGap-WaterDepth)^{\frac{1}{N}}\right]} \quad (4)$$

where: All depths are in ft.

ρ_{Miller} is bulk density in g/cm^3.

ρ_{matrix} is matrix density (default 2.65 g/cm^3).

ρ_{Water} is the density of pore water (default 1.03 g/cm^3).

$\emptyset_a$ is sediment porosity at great depth (default 0.35 p.u.).

$\emptyset_b$ is the sediment porosity fitting parameter equal to mud line porosity minus 7 (default 0.35 p.u.).

K is the porosity decline parameter (default 0.0035).

N is the curvature parameter (default 1.09).

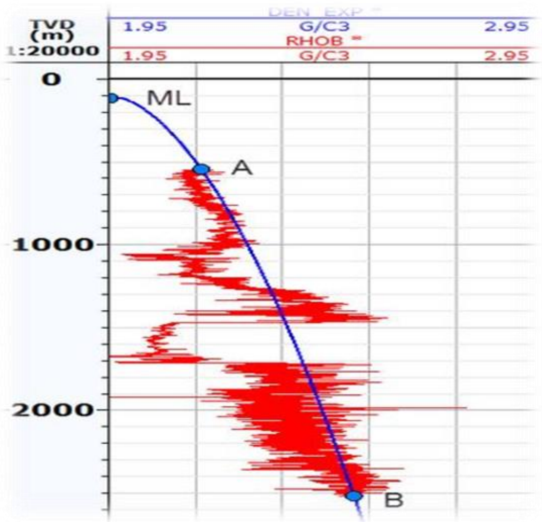

Figure 4. An example of vertical stress using the extrapolated density method **(Schlumberger, 2015).**

2.1.3. Amoco empirical relation

The average bulk density below the seafloor is estimated by an empirical equation obtained from statistical data from the Gulf of Mexico and for best-fit density by ρ mudline and α.

$$\rho_{Amoco} = \rho_{\ mudline} + Ao \times \left[{}^{(TVD - Air\ gap\ - Water\ Depth)}/_{3125}\right]^{\alpha} \quad (5)$$

where: ρ_{Amoco} density in ppg, ρ mudline is mud density in ppg, and α is the exponent coefficient (default 0.6) **(Schlumberger, 2015).**

2.1.4. Gardner density

Density was calculated using sonic or seismic data, and When compressional slowness is supplied as input, it is transformed to velocity before being used in the equation below. By adjusting, it can get the best fit for the density data **(Schlumberger, 2015).**

$$\rho_{Gardner} = \alpha \times V^{\beta} \tag{6}$$

where: ρ Gardner is in g/cm^3.
α and β are two fitting parameters named velocity factor and velocity exponent, respectively.
V is sonic or seismic formation velocity in ft/s.

2.1.5. Wendt non-acoustic method

This method measures density without using sonic data, entirely depending on density, as shown in the equation below as a function of depth **(Schlumberger, 2015).**

$$\rho_{Wendt} = Density\ Bias + Density\ Scalar \times WendtMultiplier \times (2.026 + 0.000025063 \times TVDMBL) \tag{7}$$

where: Depth is in ft, and bulk density is in g/cm^3.
Wendt Multiplier is the Multiplier factor (default 1.0).
Density Scalar is density scalar in g/cm^3 (default 1.0 g/cm^3).
Density Bias is density shift in g/cm^3 (default 0.0 g/cm^3).
TVDBML is TVD below the mudline in ft.

2.1.6. Traugott density method

This is an empirical model of decreasing porosity with depth developed by David Scott and Martin Traugott (Amoco, 1988) based on an exponential fit of Gulf Coast Miocene sediment density data collected by Classen, 1966, **(Traugott, 1997).**

$$\sigma_v = \frac{1}{2}(\sigma_v + \rho_b \times (D_{new} - D_{old}) \times 0.43353 + \sigma_{vtemp}) \tag{8}$$

2.1.7. Average density method

In this mode, it can draw a density curve with a constant value along with the depth. It can use different average densities by zone, and Techlog takes the average density from the input density curve **(Schlumberger, 2015).**

3. Results and Discussion

The fourth track, SVERTICAL-EXT, refers to the vertical stress calculation by this approach. The sixth track with blue color was the density calculation by this method relies on two locations, as shown in **Fig.5,** and the input data is only density log. The extrapolated density measurement used an average gradient for the real density, which can introduce good results for vertical stress at shallow depths.

The total porosity log and density log were used as the method's input data, which are depicted in **Fig.6** above. The total porosity was calculated using neutron and density log in the second track PHIT-ND, and vertical stress was calculated using this method in the fourth track. Bulk density was predicted using this method in the sixth track in black color and gave a good fit with the real density in red, which may have been the best indicator of vertical stress in deep depth. As can see in the second track in **Fig.7** below, Gardner's method used a sonic log (compression wave log) as input data. This method's vertical stress was determined on the fourth track, and the bulk density calculation using it was shown on the sixth track. However, the problem with this method is that it doesn't start from the surface and instead relies only on sound log data, which may result in incorrect vertical stress values. For example, the vertical stress at a depth of 2500 m does not exceed 5000 psi, which may be inaccurate. **Fig. 8** shows the calculation of density using various methods. The first track was colored blue for the Amoco method, the second was colored green for the Wendt non-acoustic method, the third was colored black for the Traugott average method, and the final track was colored orange for the average method. All of these methods employed a straight line as the observed density and only used a density log as an input, which was incorrect for calculating vertical stress.

Table (2) indicates that since the extrapolated density approach provides the optimum gradient for the bulk density at shallow depth, it may produce satisfactory results for vertical stress. However, the Miller density approach has a good match with real density at deep depths. The vertical stress values by miller are lower than those obtained by extrapolating, and this may be due to the poor gradient of this method at shallow depths. Gardner's approach incorrectly displays minimum values at great depths. While other methods provide numbers that are similar because these methods use constant bulk density values that start at the surface and continue to the desired depth; however this is incorrect.

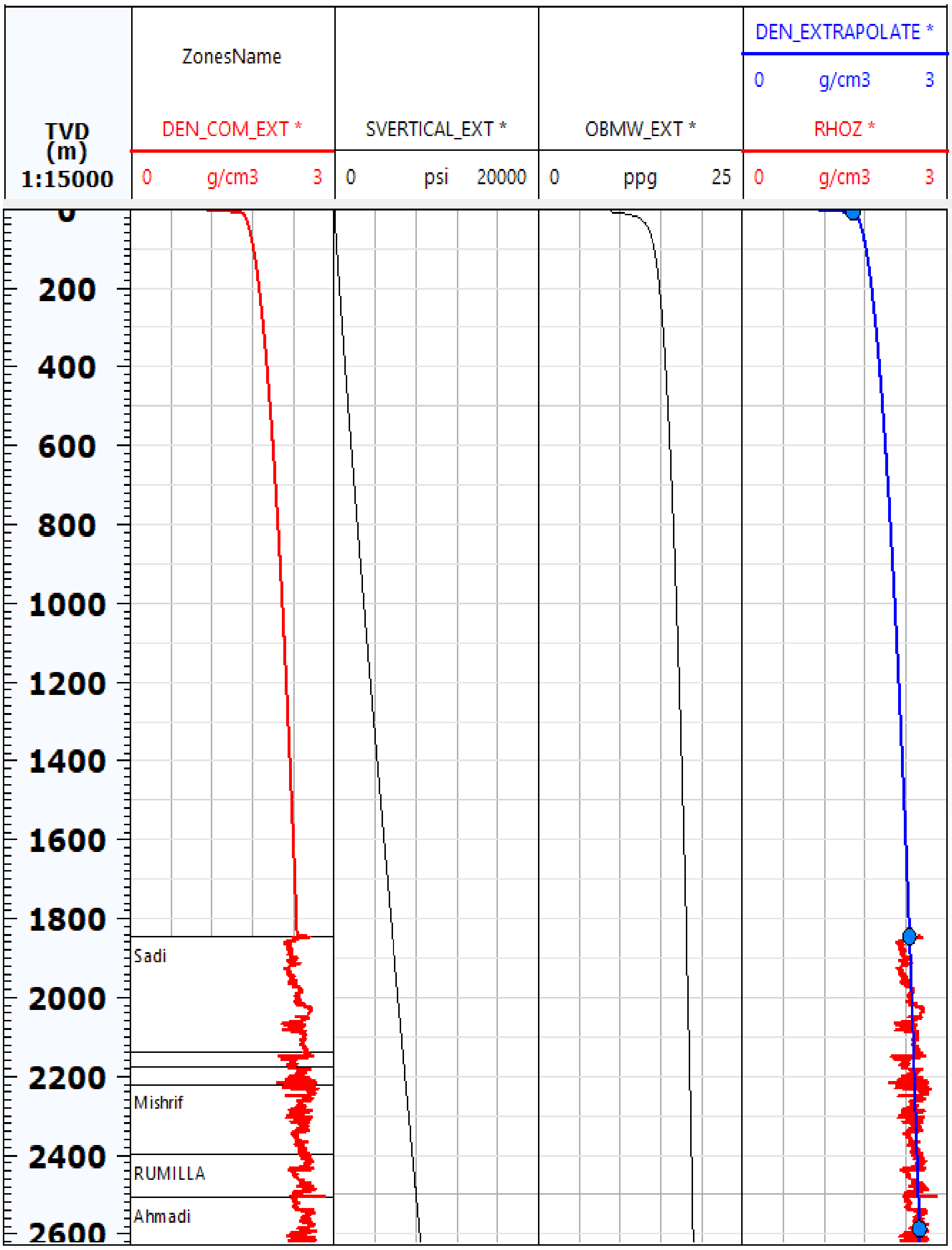

Figure 5. Vertical stress by Extrapolated Density Method.

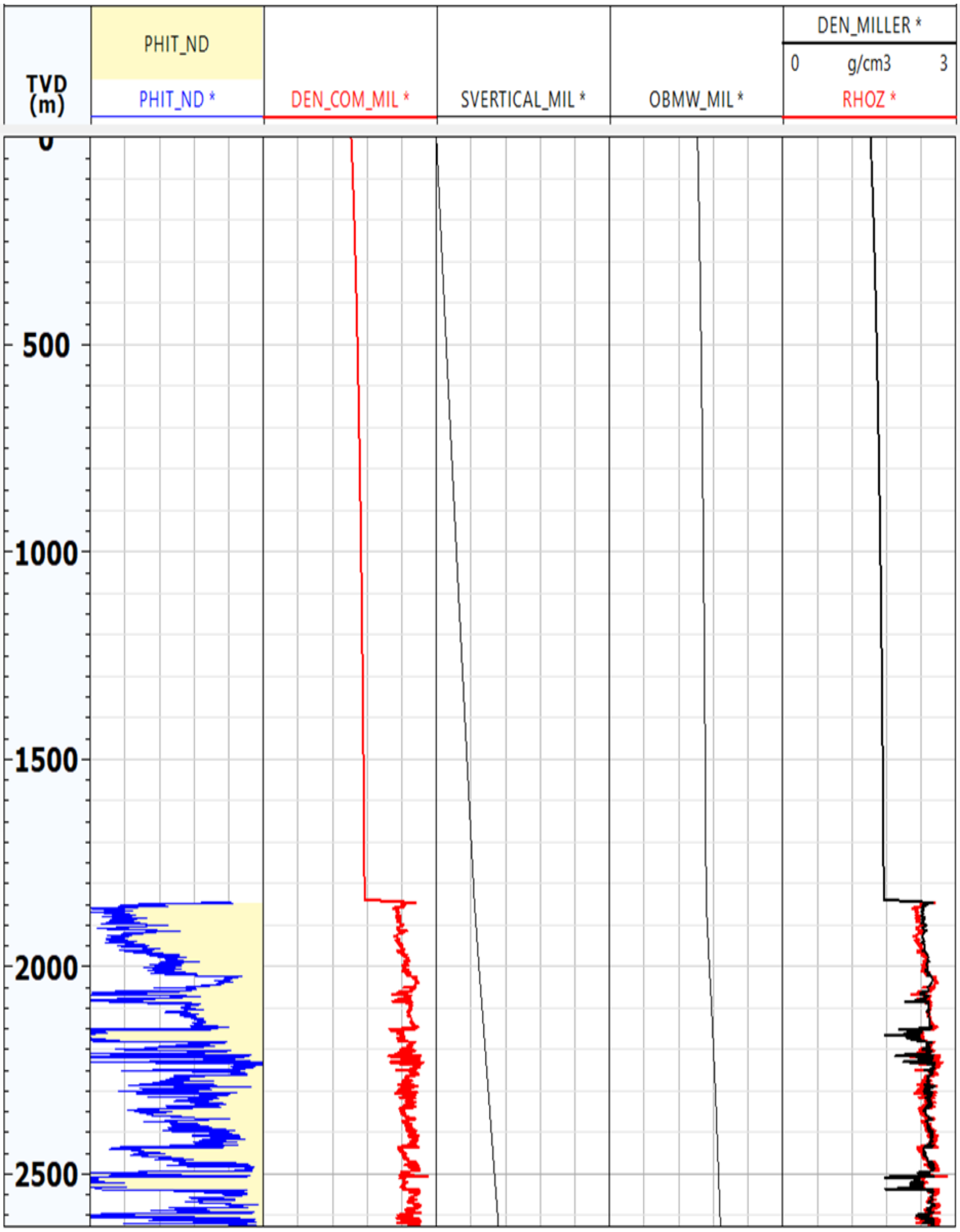

Figure 6. Vertical stress by miller density method.

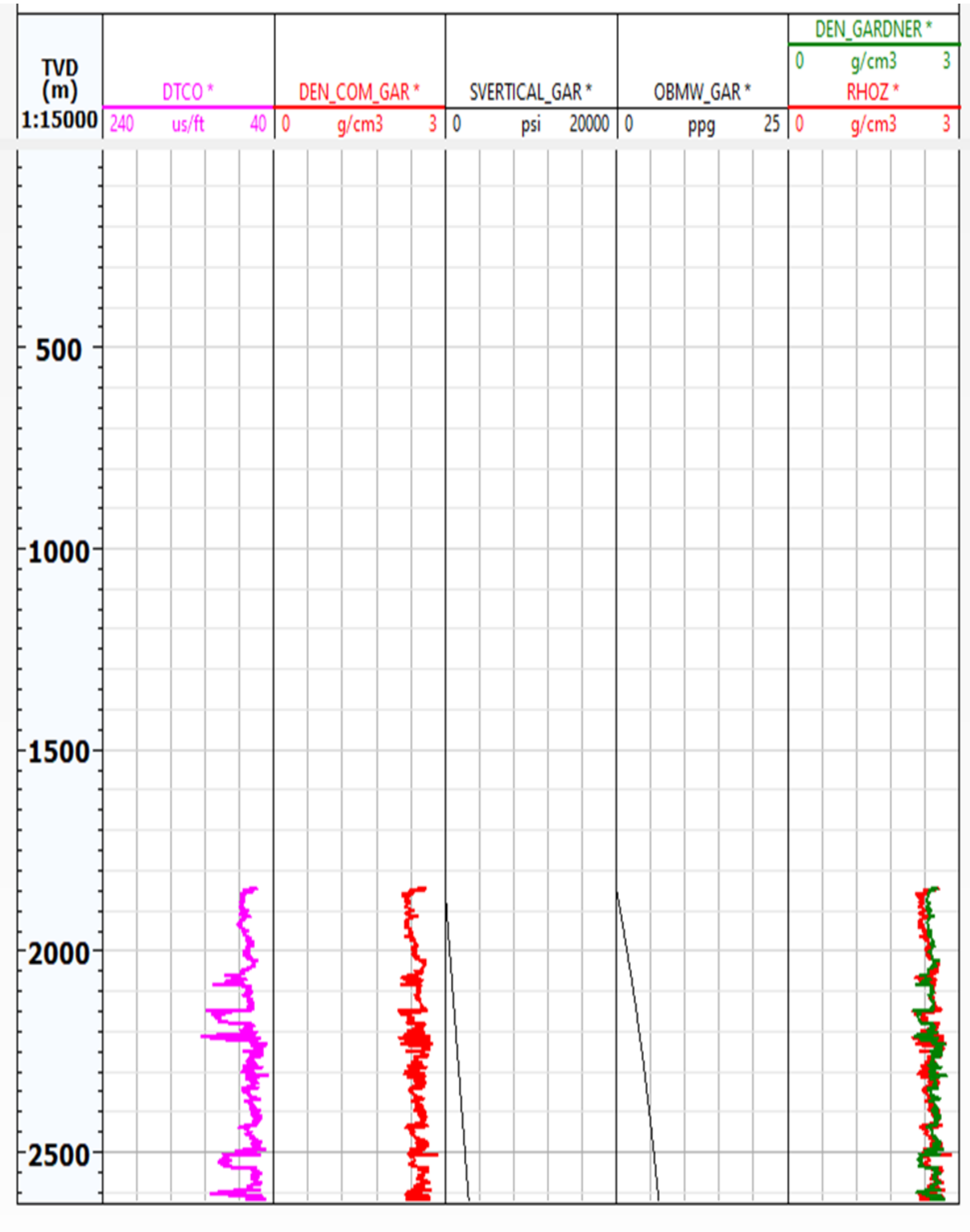

Figure 7. Vertical stress by Gardner method.

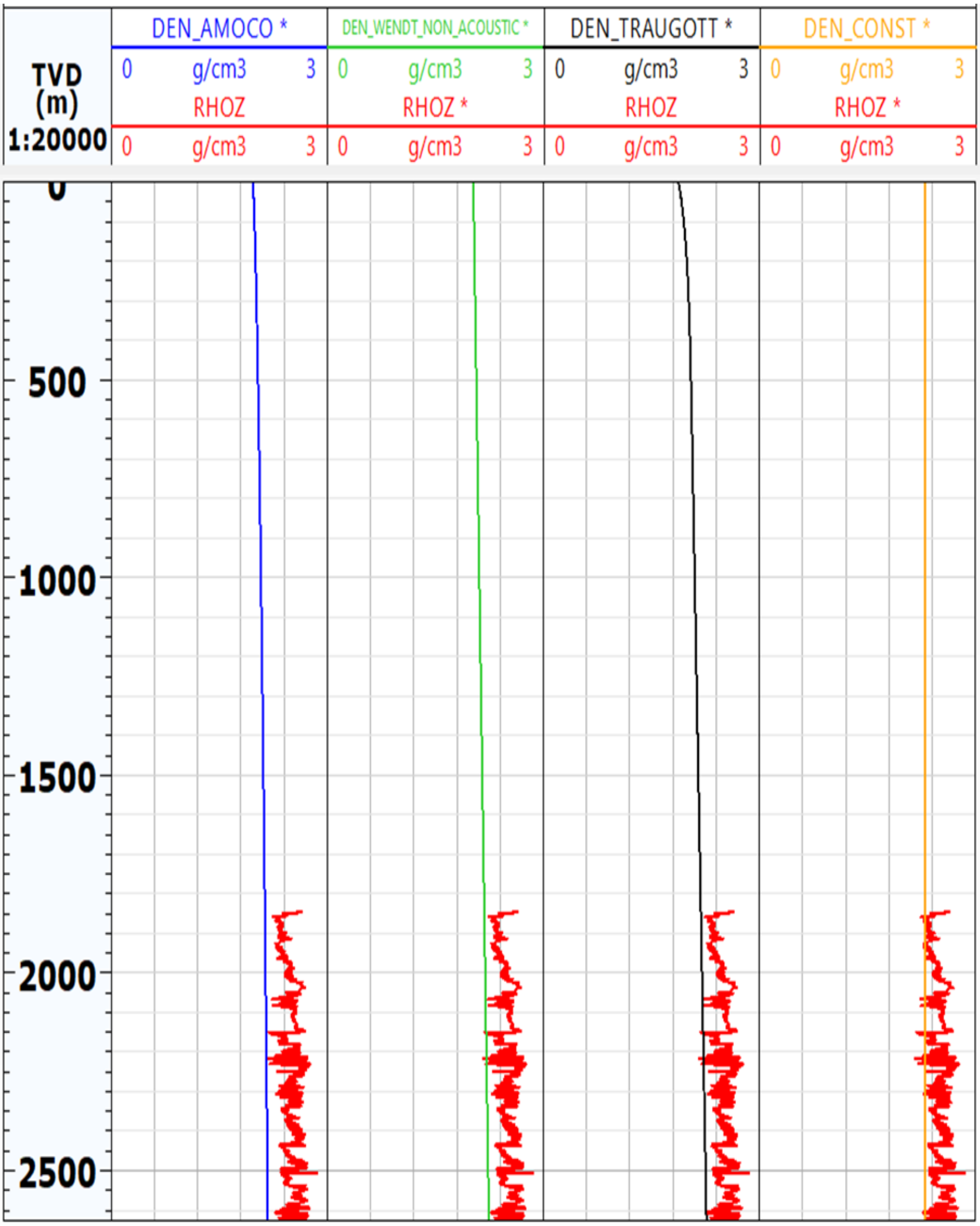

Figure 8. Density calculation by a different method.

Table 2: Range of vertical stress in (psi) unit at each formation.

No	Formation	Extrapolate	Miller	Amoco	Gardner	Wendt	Traugott	Average
1	Sadi	5500 - 6600	5200-6230	5500-6540	2700-3700	5500-6500	5400-6400	6000-7000
2	Tanuma	6600-6780	6230-6400	6540-6680	3700-3860	6500-6650	6400-6600	7000-7180
3	Khasib	6780-6900	6400-6550	6680-6800	3860-4000	6650-6800	6600-6760	7180-7300
4	Mishrif	7000-7600	6550-7180	6800-7400	4000-4650	6800-7460	6760-7400	7300-7990
5	Rumailla	7600-7900	7180-7580	7400-7800	4650-5050	7460-7850	7400-7790	7990-8366
6	Ahmadi	7900-8330	7580-8000	7800-8280	5050-5480	7850-8285	7790-8230	8366-8804

4. CONCLUSIONS

- Vertical stress is an important prediction since, for the previous 40 years, this stress has been used as an input by pore pressure and geomechanical models.
- The average line and two-point shallow and deep points may provide the best results for obtaining vertical stress values using the extrapolated density technique.
- Gardner's approach produces excellent results compared to actual bulk density, but it is undesirable due to its reliance on sonic logs and calculations starting from their depth, which results in inaccurate predictions of vertical stress.
- The Miller density method provides better results with actual bulk density at a deep depth.
- The Miller density method at shallow depth provides a poor gradient.
- The other approaches, which rely on straight lines for calculation and could result in incorrect numbers, produce very poor predictions of vertical stress.

Acknowledgments
The authors would like to express their gratitude to the Petroleum Research and Development Center (PRDC) for contributing to this study.

Nomenclature
Ao = fitting parameter, dimensionless.
BT = Bit size, in.
D_{new} and D_{old} = new and old depth, ft.
DTCO = compressional sonic log, us/ft.
DTSM = shear sonic log, us/ft.
g= gravity acceleration, m/s^2.
GR = gamma ray log, API.
K = porosity decline parameter, dimensionless.
N = curvature parameter, dimensionless.
PHIT-ND =Total porosity, dimensionless.

RHOZ= density log, g/cm3.
Sv = vertical stress, psi.
SVERTICAL-EXT = Vertical stress by extrapolated, psi
TVD = true vertical depth, m.
V= sonic velocity, ft/sec.
$\emptyset_{miller}$= miller porosity, dimensionless.
α= fitting parameter, dimensionless.
β= fitting parameter, dimensionless.
ρ = bulk density, g/cm3.
σv= vertical stress, psi.

REFERENCES

Aadnoy B., and Looyeh, R., 2011. Petroleum rock mechanics: drilling operations and well design. Gulf professional publishing.

Al-Ameri, k., Thamer, Amer Jassim, Al-Khafaji, and John Zumberge, 2009. Petroleum system analysis of the Mishrif reservoir in the Ratawi, Zubair, North and South Rumaila oil fields, southern Iraq, *GeoArabia*, 14(4), pp.91-108, doi.org/10.2113/geoarabia140491.

Al-Ameri, T. K., Jafar, M. S., and Pitman, J., 2011. Modeling Hydrocarbon Generations of the Basrah Oil Fields. In Southern Iraq, Based on Petromod with Palynofacies Evidence, *AAPG Annual Convention and Exhibition*, Houston, Texas, pp.10-13, doi.org/10.3997/2214-4609-pdb.287.1176781.

Bell, J. S., 2003. Practical methods for estimating in situ stresses for borehole stability applications in sedimentary basins, *Journal of Petroleum Science and Engineering*, 38(3-4), pp.111-119. doi.org/10.1016/S0920-4105(03)00025-1.

Daham, M.H., 2021. A Prediction Formula for The Estimation of Sediment Load in The Upper Reach of Al-Gharraf River, *Journal of Engineering*, 27(5), pp.63-74. doi.org/10.31026/j.eng.2021.05.05.

Fjar, E., Holt, R. M., Horsrud, P., and Raaen, A. M., 2008. Petroleum related rock mechanics: Elsevier.

Jaeger, J. C., Cook, N. G., and Zimmerman, R., 2009. Fundamentals of rock mechanics, John Wiley & Sons.

Mohajjel, Mohammad, and Christopher, L., Fergusson, 2000. Dextral transpression in Late Cretaceous continental collision, Sanandaj–Sirjan zone, western Iran, *Journal of Structural Geology*, 22(8), pp. 1125-1139.

Mohammed, Q. S., 2022. Dynamic Behavior of Machine Foundations on layered sandy soil under Seismic Loadings, *Journal of Engineering*, 28(8), pp.1-20. doi.org/10.31026/j.eng.2022.08.01.

Schlumberger., 2015. Techlog Pore Pressure Prediction and Wellbore Stability Analysis Workflow, Solutions Training.

Scholz, C. H., 2019. The mechanics of earthquakes and faulting, Cambridge University Press.

Traugott, M., 1997. Pore/fracture pressure determinations in deep water, *World Oil*, 218(8), pp.68-70.

Zoback, M. D., 2010. Reservoir geomechanics, Cambridge University Press.