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Static Young's Modulus Prediction of Shale Formations Using Well Log Data: A case study from Rumaila oilfield

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Abstract

Static young modules (Est) can be measured in the lab on real cores. Moreover, open-hole log data can be utilized to obtain the dynamic Young's modulus (Edyn). However, dynamic Young's modulus is affected by different rock properties. Thus, dynamic rock properties must be changed to static moduli using empirical equations. In this study, an experimental dataset from shale formation has been used to produce a reliable and accurate correlation for estimating static Young's modulus from log data alone, without the need for core measurements. We used 144 data points from log data to create the new correlations. We compared the results of the new correlation with earlier correlations in the literature. The findings demonstrated that, in contrast to those in the literature, the proposed empirical correlation is accurate and dependable with a correlation coefficient (RSQ) of 0.97% and an average absolute error (AAER) of 9.69%. Therefore, the new correlation can be used to improve shale formation fracturing operations, resolve issues related to shale instability, and optimize drilling procedures such as bit type and drilling parameters.

Keywords: Static Young modules, dynamic Young's modulus, shale formation, well log.

التنبؤ بمعامل يونغ الساكن لتكوينات السجيل باستخدام بيانات الجس البئري: دراسة حالة من حقل الرميلة النفطي

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الخلاصة

يمكن قياس بمعامل يونغ الساكن في المختبر على نماذج اللباب الصخري. علاوة على ذلك، يمكن استخدام بيانات الجس البئري للحصول على معامل يونغ الديناميكي، مما يتيح التقدير المستمر للخصائص المرنة. ومع ذلك، يتأثر معامل يونغ الديناميكي بخصائص الصخور المختلفة. وبالتالي، يجب تغيير خصائص الصخور الديناميكية إلى معاملات ساكنة باستخدام المعادلات التجريبية . في هذه الدراسة، تم

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استخدام مجموعة بيانات مختبرية من تكوين السجيل لإنتاج علاقة موثوقة ودقيقة لتقدير معامل يونغ الساكن من بيانات الجس البئري وحدها، دون الحاجة إلى قياسات اللباب الصخري. تم استخدام 144 نقطة من بيانات الجس البئري لإنشاء العلاقة الجديدة. تمت مقارنة النتائج المستحصلة من العلاقة الجديدة مع العلاقات المنشورة سابقا. أظهرت النتائج أنه، على عكس تلك الموجودة في الأدبيات، فإن العلاقة المقترحة دقيقة ويمكن الاعتماد عليها مع معامل ارتباط (RSQ) قدره 0.97% ومتوسط خطأ مطلق (AAER) قدره 9.69%. لذلك، يمكن استخدام العلاقة الجديدة لتحسين عمليات تكسير التكوينات، وحل المشكلات المتعلقة بعدم استقرار تكوين السجيل، واختيار الحفر الامثل مثل اختيارنوع البريمة و معامل الحفر.

1. Introduction

One of the significant challenges encountered when drilling the shale formation in various Iraqi oil fields is often cited as shale instability such as borehole collapse and poor log quality, and stuck pipe could be costly. It is essential to comprehend the mechanical characteristics of shale to optimize hydraulic fracturing design, wellbore stability assessments, and drilling processes [1-5]. The mechanical characteristic that determines a material's strength is referred to by the terms elastic modulus, Young's modulus, and modulus of elasticity. Rocks' elastic properties are measured using both dynamic and static techniques. The core samples are subjected to triaxial stresses in the static method gradually until rupture occurs [6]. The proportion of the stress exerted on a material to the resulting strain caused by the imposed stress is known as static Young's modulus (Est) [7]. In geomechanical modelling, static elastic parameters are a common and credible choice [8]. However, measuring them is difficult because good rock core specimens are needed, and these might not be found in shale formations. Since shale formations are frequently not prioritised in oil exploration, few specimens of this rock are available for testing from deep boreholes. This is a result of the additional expenses related to coring operations. Thus, developing techniques that give continuous elastic properties using well-logs data over the whole formation is critical. The dynamic method determines the elastic properties using laboratory or field measurements of the shear wave velocity, bulk density, and compressional wave velocity. The static and dynamic moduli of the identical rock are never the same; typically, the static Young's modulus is less than the dynamic one [5, 9-11]. For weak rocks, the difference is significant, and it gets smaller as confinement increases [12]. To explain this discrepancy, numerous explanations have been given. This discrepancy results from differences in the amplitude of deformation (strain) between the two types [13-15]. In addition to being affected by the rock's mineral composition and physical origin, according to [16-20], the dynamic modulus is less impacted by microcracks than the static modulus.

Therefore, it is crucial to determine the empirical relationship between dynamic and static parameters to effectively and consistently estimate the static elastic properties of rocks located along a wellbore [21-26].

Several formulas have been created to illustrate the relationship between the dynamic and static Young's moduli [27-29]. The subsequent equation represents the typical structure of previously suggested formulas for the estimation of static Young's modulus:

$$E_{st} = a\, E_{dyn} + b \tag{1}$$

Where the constants "a" and "b" depend significantly on the kind of rock.

Table 1 provides an overview of empirical relationships for calculating the static modulus in a shale formation based on the dynamic modulus.

According to the literature review, there is currently no universal formula for determining the static Young's modulus from well-log data; each of those correlations' applicability is restricted to a specific kind of rock and certain conditions.

This study aims to establish a new relationship between the dynamic (from well-log data) and static elastic moduli for shale rocks within the Rumaila oilfield.

Table 1: Previous Correlations for Static Modulus Prediction from Dynamic Modulus in Shale Formation.

Equation	Static Modulus Equation	Reference
(2)	$E_{st} = 0.018\ E_{dyn}{}^{2} + 0.422E_{dyn}$	Lacy [8]
(3)	$E_{st} = 0.867E_{dyn} - 2.085$	Brotons et al. [30]
(4)	$E_{st} = 0.0158\ E_{dyn}{}^{2.74}$	Ohen [31]
(5)	$E_{st} = 0.25E_{dyn}{}^{1.29}$	Moradian and Behnia [32]
(6)	$E_{st} = 1.05\ E_{dyn} - 3.16$	Christaras et al. [33]

2. Methodology

2.1 Data processing and analysis

An assemblage of 144 well log data points was acquired from a vertical well section of shale formation, covering a depth range of 3082 m to 3103 m. The dataset includes well log measurements of bulk density (RHOZ), shear wave velocity (DTSM), compressional wave velocity (DTCO), Gamma Ray (GR) and six triaxial test measurements of static Young's modulus (Est) for the shale sample. The dataset is subjected to statistical analysis, and the results are reported in Table 2.

Table 2: Statistical Analysis of The Core and Well Log Data from the Shale Formation

Property	Minimum	Maximum	Mean
DTSM (us/ft)	114.45	185.3	169.16
DTCO (us/ft)	66	98.98	86
RHOZ (g/cm^3)	1.74	4.83	3
Gamma Ray (gAPI)	71	162.88	127.37
Edyn (GPa)	17	46	21.81
Est (GPa)	1.93	12.17	5.85

2.2 Static-Dynamic Young's Modulus Relationship

The procedure used to calculate the static Young's modulus of the formation based on dynamic elastic values is shown in Figure (1). This figure explains how to compute the static Young's modulus (from core data) and dynamic (from well-log data).

To begin with, the dynamic modulus is determined by utilizing the bulk density log and sonic logging techniques. The formula developed by [34] is used for the computation of the dynamic Young's modulus (Edyn):

$$E_{dyn} = \rho {v_s}^2 \left(\frac{3{v_p}^3 - 4{v_s}^2}{{v_p}^2 - {v_s}^2} \right) \tag{7}$$

where:

Edyn represents the dynamic Young's modulus, ρ represents the bulk density, Vp represents the compressional wave velocity, and Vs represents the shear wave velocity.

The dynamic modulus obtained from the aforementioned formula is widely recognized to have overstated values and needs to be converted into a static modulus suitable for this particular area. This is achieved by employing empirical relationships established from data collected at the laboratory scale. Then, a continuous profile of the static modulus inside the reservoir's depth will constructed by comparing the dynamic modulus acquired from log data with the static modulus observed in laboratory tests at specific depth points. An assessment will be conducted on the accuracy of the static modulus predictions for the shale formation based on previous correlations using well-log data and core sample measurements.

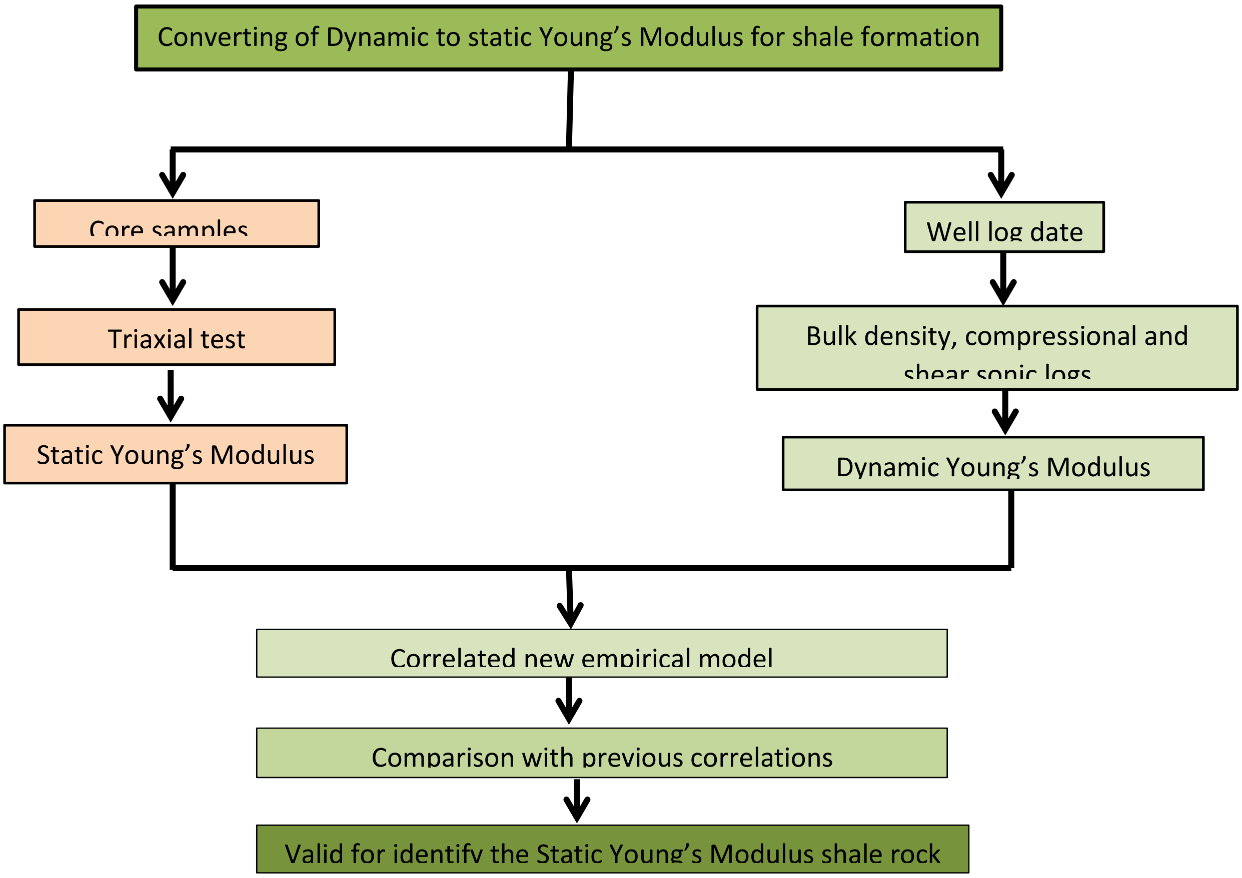

Figure 1: Workflow for Converting of Dynamic to static Young's Modulus for shale formation

3. Result and Discussion

Wellbore instability accounts for 20% of unproductive time in the oil and gas industry, mainly because of the weak strength and elevated pore pressure in shale formations. This problem presents a substantial obstacle for drilling operations. The dynamic elastic values are generally more significant than the static values due to the non-linear elastic response and parameters such as porosity, size, and fissures or spatial orientation of bedding planes. Figure 2 depicts the method employed to determine the static elastic characteristics of the formation, specifically Young's modulus by utilizing dynamic elastic data.

A new correlation is established by utilizing the measured static modulus and the corresponding dynamic modulus from the well log to estimate the static modulus for shale formation. The findings demonstrate that the new equation provides the most accurate representation of the static and dynamic modulus relationship, as shown in Figure 2. Thus, the correlation analysis between the dynamic and static elastic characteristics yielded the following relationships:

$$E_{st} = 0.3678\, E_{dyn}{}^{1.1097} \tag{8}$$

The static modulus is denoted as E_{st}, whereas the dynamic modulus is represented as E_{dyn}.

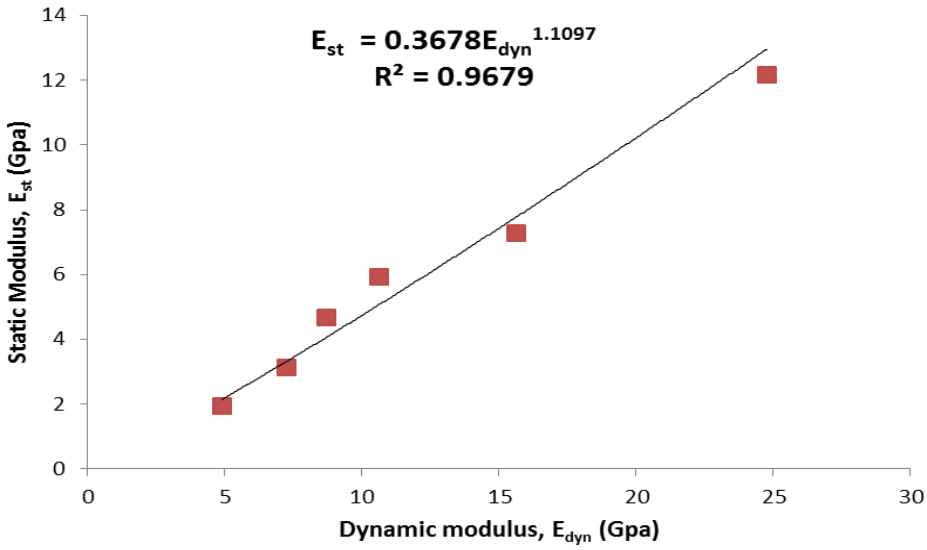

Figure 2: The new correlation for shale static modulus prediction from Dynamic Modulus

The results demonstrate that the suggestion correlation is superior to previously published correlations in accurately computing the static modulus for shale formation. Based on the results shown in Table 3 and Figure 3.

Table 3: Comparison of the Accuracy between the new and previous Correlations for Static Modulus Prediction in Shale Formation.

Correlation	AAER %
Ohen [31]	49.71
Christaras et al. [33]	28.78
Brotons et al. [30]	23.66
Lacy [8]	23.11
Moradian and Behnia [32]	11.54
New Correlation	9.69

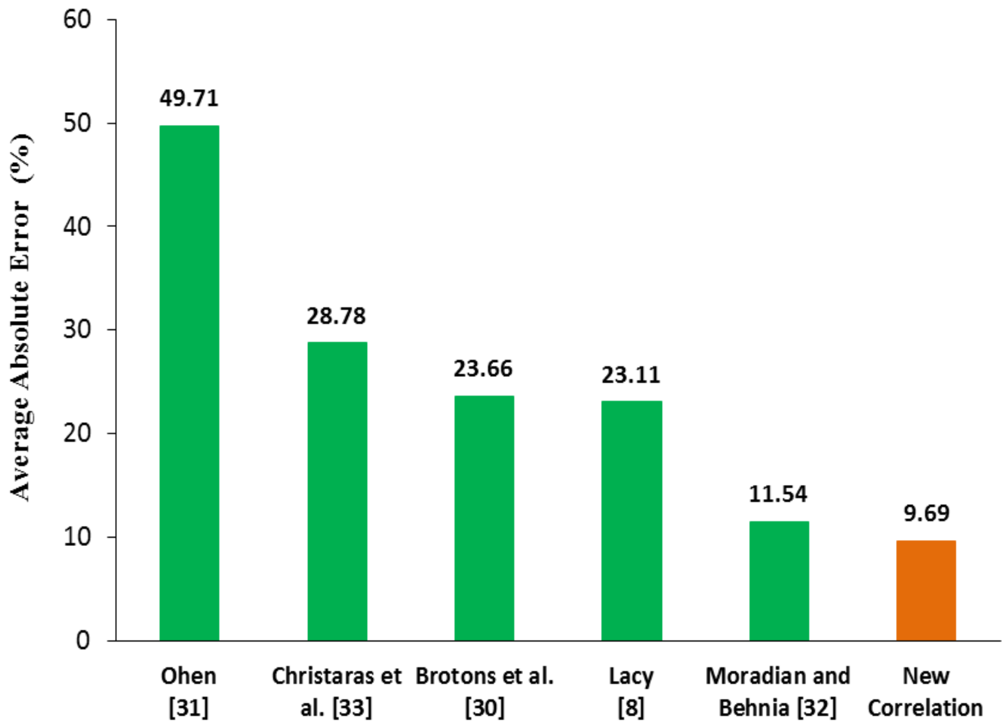

Figure 3: Accuracy of the previous and current study correlations To Predict Static Modulus.

When compared to the measured laboratory core data, the newly created correlation produced a highly satisfactory agreement for the static Young's modulus. Fig. 4 illustrates the comparison between the static modulus derived using the new correlation Eq. (8) and the prior correlations Eqs. (2 to 6).

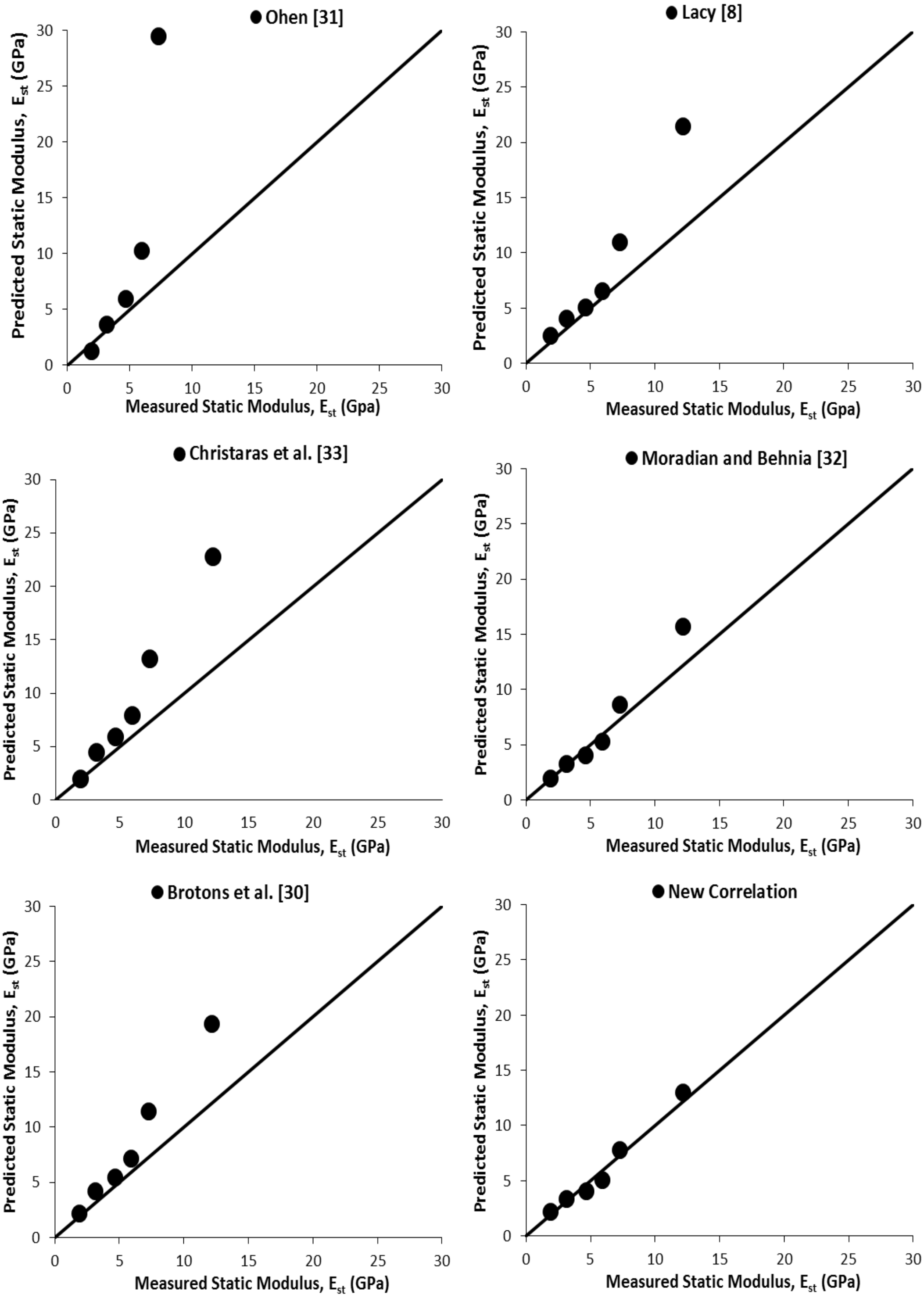

Figure 4: Cross-plots of the predicted versus measured static modulus of shale formations for the previous and current study correlations.

Ultimately, by employing the newly established correlation Eq. (8), a continuous static modulus profile is generated for the depth interval (3082 m to 3103 m) within the shale formation of the Rumaila oil field (as depicted in Fig. 5).

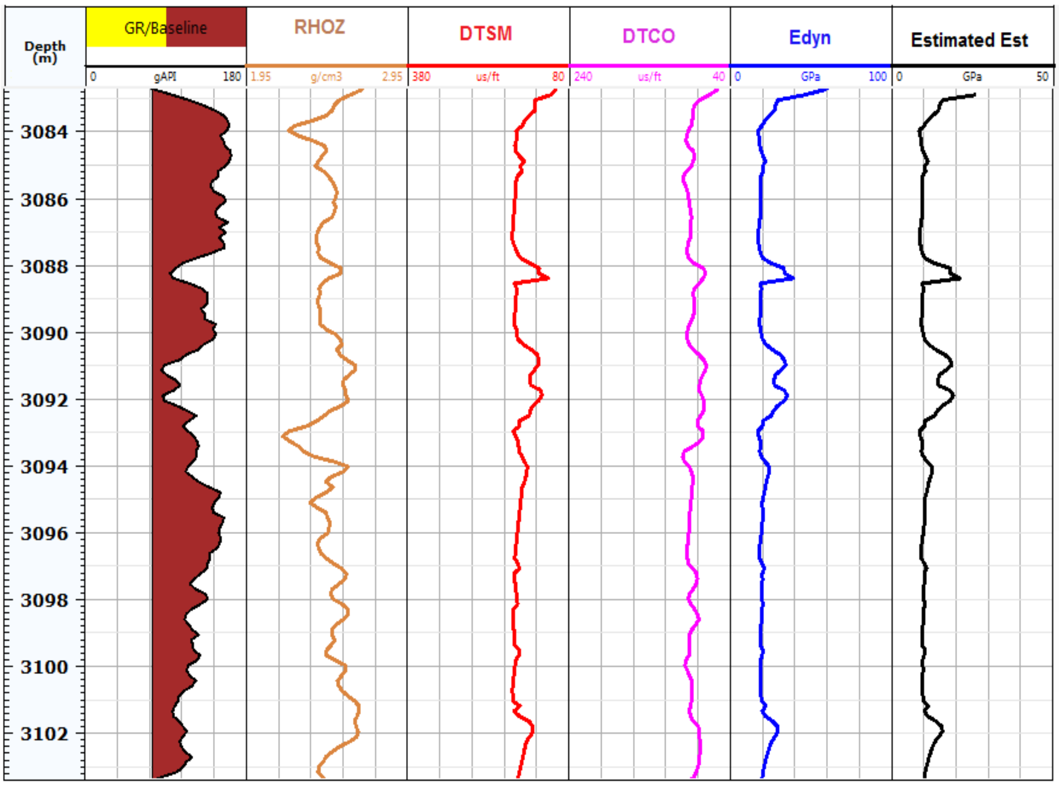

Figure 5: The computed static modulus profile for shale formation from the new correlation with the well log data and the associated dynamic modulus.

The relationship between borehole stability and this application is most prominently observed, and can be utilized at many stages of the drilling process, such as planning and ongoing monitoring throughout drilling operations.

It is important to mention that the correlation is restricted to shales; thus, it is necessary to do a lithology check. Due to the extensive diversity in shale properties and composition, it is necessary to use caution when applying the correlation in various situations. To obtain such a generalization, it is necessary to do comprehensive testing and analysis of the correlations.

4. Conclusions

When considering the area for enhanced drilling performance, it is important to take into account the elastic characteristics as a fundamental criterion [35-37]. The elastic parameters can be estimated using measurements conducted under static conditions and computed using the observed density and recorded velocity of compressional and shear waves in the borehole. While static methods are considered the most precise means of measuring elastic modulus, they are also the most costly and time-consuming [38-43].

Various correlations have been suggested for estimating the static modulus based on the dynamic modulus. Due to their formation-specific nature, most of these relationships are not applicable. In this study, we have created a new correlation to forecast the static Young's modulus for shale formations in an Iraqi oil field based on the dynamic modulus.

To be precise, the average absolute error was 9.69%, and the correlation coefficient (RSQ) was 0.97%. In addition to lowering the cost of estimating elastic properties for shale formation, the new correlation allows for continuous depth profiles for static Young's modulus.

This correlation can serve as an engineering tool to enhance the accuracy and continuity of estimations for the elastic characteristics of shales. However, it is essential to note that the reliability of this correlation should be verified when applied to the same geological and geographical regions. The correlation is primarily used in the assessment of borehole stability, including planning, drilling, and post-analysis. However, it also has potential uses in optimizing drilling operations, such as determining the appropriate bit type and parameters, as well as evaluating overburden compaction.

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