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# Perfect Layer Identification Based on Experimental Tests and Geomechanical Evaluation

*Amani Ihsan**, *Nagham Jasim Al- Ameri*

*Department of Petroleum Engineering, College of Engineering, University of Baghdad, Iraq*

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**Abstract**

One of the most critical stages in reservoir development is to identify perfect layer for hydraulic fracture operation. Perfect layer must be choice based on the better distribution of both petrophysical and geomechanical properties. Geomechanics is of great importance in the petroleum industry, as it explains the effects of rock interaction, stress distribution, failure criteria, and rock strength parameters. 1-D MEM calculations were conducted in this study for many formations, the procedure to build the model and selection of the perfect layer is based on determined geomechanical properties, petrophysical properties, and stress distribution. Furthermore, an experimental evaluation of the presented layers are conducted in this study based on different tests such as X- Ray analysis, Energy-dispersive X-ray spectroscopy (EDS), scanning electron microscopic (SEM) image and thin section (TS) image. In additional, 1-D mechanical earth model (1-D MEM) have been constructing using TECHLOG software to give an integrated evaluation of the interested layers. The results show the most critical factors effect on best layers selection as indicated from 1-D MEM are Young modulus E and the rock compressive strength UCS. Also, horizontal stresses are a crucial parameter for best layer selection due to its effect on the resulted fractures direction. Close analysis of SEM and TS test of the core samples indicate that the studied layers show low sensitive to stress. SEM and Ts test are valuable in mechanical properties analysis. High rock porosity indicated as vuggy pore partially filled with sparry calcite can affect the resulted value of Poisson ratio as shown in the studied core samples.

***Keywords:*** *Mechanical earth model; X- Ray analysis; Scanning electron microscopic; Thin section; EDS.*

## 1. Introduction

Applying rock mechanics in the oil and gas field can lead to economic development and improvement. In the application of rock mechanics, rock failure criterion is one of the most important issues that must be checked during drilling operations to know the condition of the rocks, prevent malfunctions in drilled rock structures, and help to predict the direction of hydraulic fracture. Many failure criteria were developed to estimate rock failure, such as the Mohr-Coulomb and Hoek-Brown parameters, which do not consider intermediate principal stress, while Modified Lade and Mogi Coulomb take into consideration the intermediate principal stress and its effect on rock failure [1]. When drilling well different types of hydraulic fractures are created. Hydraulic fractures may be transverse, longitudinal, and oriented fractures. These types of hydraulic fracture created depend on the well direction with respect to the minimum in-situ stress [2].

Nowadays, field development is based on static reservoir characterization, which includes the distribution of initial stresses and mechanical properties of the field, as well as numerical reservoir modeling to analyze the dynamic evolution of stresses [3]. In order to determine the orientations and intensities of stress in the far-field, as well as the pore pressure and mechanical properties of the rocks, must necessary to create 1D Earth Mechanical Model (MEM). The Traditional 1D geomechanical models analysis are limited, especially for complex geological structures and wellbore trajectories [4]. They can lead to distorted outputs and inefficient workflow due to vertical distribution only. a generic workflow was proposed for a calibrated 3D geomechanical model that leverages existing 1D models and geological data to create a more accurate and efficient solution for candidate layer selection. Developing tight reservoirs is challenging due to stress and geomechanical properties impacting on horizontal well placement and hydraulic fracturing design [5]. The authors propose incorporating permeability sensitivity to stress into layer selection for horizontal wells and optimizing hydraulic fracturing parameters. Optimized the best layer for hydraulic acid fracturing in tight carbonate reservoir is a real challenge because of low production from the narrow reservoir throat due to the limited fractures [6]. Injection has been created fractures with desired geometry (length, height, width) using optimized injection parameters (flow rate, volume, stages) of the acid fracturing fluid. Experimental examination of the rock is an essential step in successful geomechanical evaluation for perfect layer choice [7]. The importance of rock mechanical properties for reservoir development techniques related to tight reservoirs can be addressed [8]. The solution proposed is to find correlations that can be used to estimate important geomechanical properties from other data. The researcher summarized experimentally derived correlations for estimating the shear velocity, Young's modulus, Poisson's ratio, and compressive strength. They also introduced a correlation to convert dynamic elastic properties from log data to static elastic properties. Most of the derived equations showed good fitting to measured data, but some equations showed scatters due to the presence of certain minerals in the core samples. The brittleness index (BRI) was also studied to indicate the ductile behavior of the core samples. The results showed that the samples ranged from moderate to high brittleness, and the difference in BRI was due to the presence of certain minerals. The proposed correlations were compared to other correlations from the literature and showed good matching, which explains the accuracy of the proposed equations. used measured mechanical properties to obtain important correlations that can be used for other carbonate reservoirs. The proposed equations work well for low porosity-low permeability samples. The brittleness index is calculated based on Young's modulus and Poisson's ratio and can be used to estimate a rock's ability to fail without compressive strength measurements. Lastly, these criteria are used to determine candidate intervals and a hydraulic fracturing simulation model.

Exploration operations in the field of the interested area began in 1960 in the EB region by the using seismic surveys. The S, T, and KH formations (carbonate) are essential reservoirs within the field that contain large amounts of hydrocarbons and consisting mainly of limestone and sandstone. The petrophysical property behavior of the formation varies with stress, exhibiting heterogeneous characteristics. These formations contain high porosity and low permeability, which causes a decrease in the production rate over time. One approach to this problem is to use hydraulic fracture to increase permeability. This is one of the most significant ways for increasing productivity. The nature of this reservoir makes development difficult; the success of any suggested development plan is heavily reliant on the selection of appropriate layers for vertical well placement and the determination of optimal hydraulic fracturing design parameters. Figure 1 illustrated the stratigraphic units within the studied field.

## 2. Experimental rock evaluation

### 2.1. Thin section and scanning electron microscope (SEM)

Thin section (TS) and scanning electron microscope (SEM) are useful tool for accurate estimation and evaluation of rock mechanical properties. These testing are conduction for a very thin materials of the rock samples. These tests have been conducted in the current study for two samples from KH and T layers as shown in Fig. 2. The results are a brief description of the tested samples in term of rock microfacies and pore geometry analysis. A full description for the tested samples are given as follows:

**A. T formation sample** as described in TS is consisted of micrite more than 4um and it is selectively recrystallized to microsparite as shown in Fig.3. Mineral constituents represent 100% calcite, 65% including groundmass and 35% fossils iron. Therefore, the rock is classified as carbonate.

**B. KH formation sample** is consisted of micrite more than 4um and it is selectively recrystallized to microsparite as shown in Fig.4. Mineral constituents represent 100% calcite, 70% including groundmass and 30% fossils iron. Depending on this test can classify the rocks as the carbonate rocks.

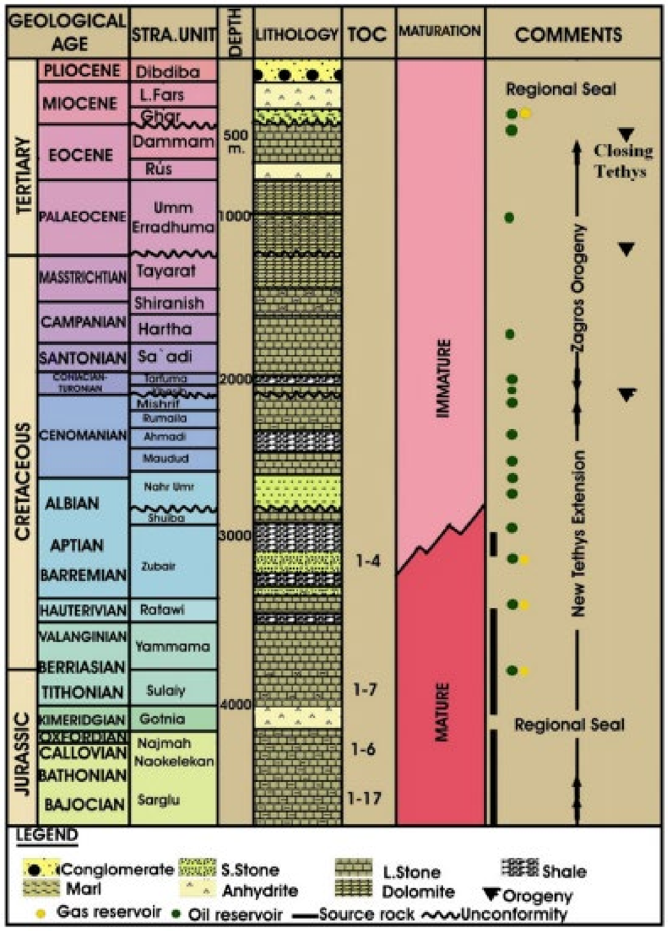


Figure 1. Stratigraphic column of the studied reservoir. [9]

## 2.2. Scanning electron microscope

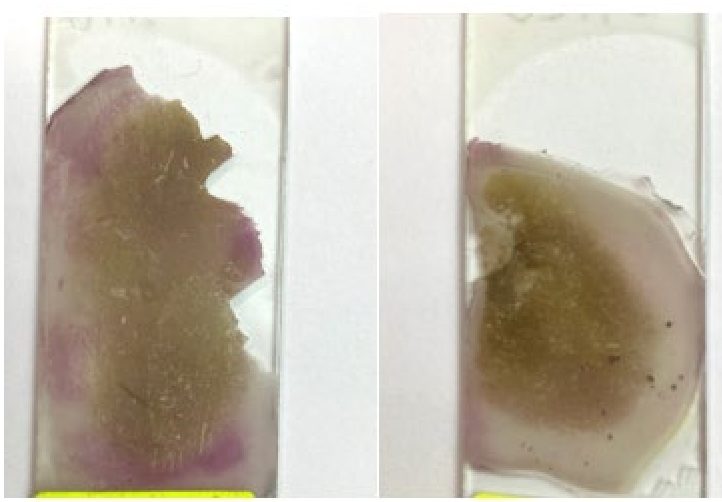

Figure 2. Microscopic image of KH and T cutting.

(SEM) this tool explains rock structure. It has samples that show a normal trend in the permeability-stress relationship in the T/KH reservoir. This layer shows low sensitivity of these to stress is illustrated in Figures 2, 3, and 4 due to vuggy pores partially filled with sparry calcite shown in the test results.

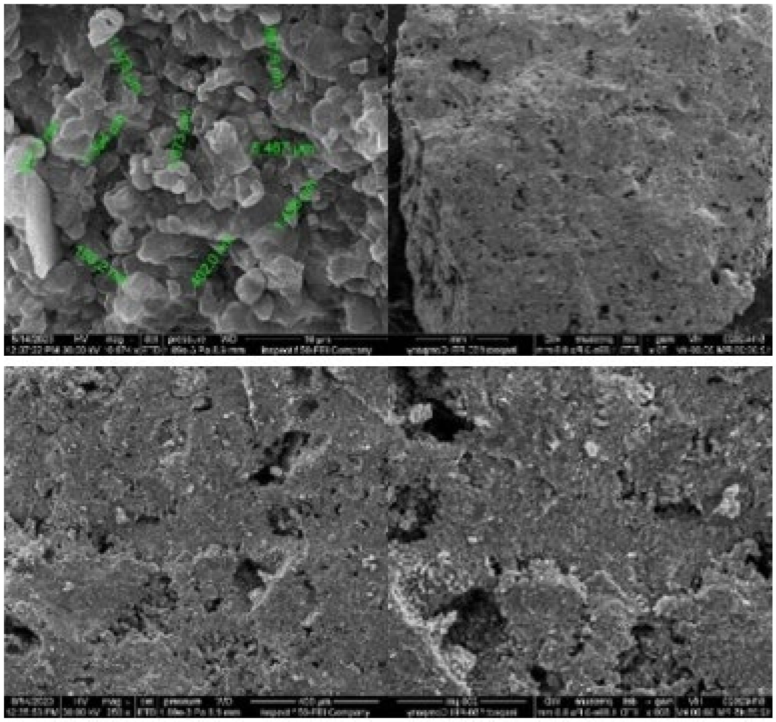

Figure 3. Thin section image for T formation.

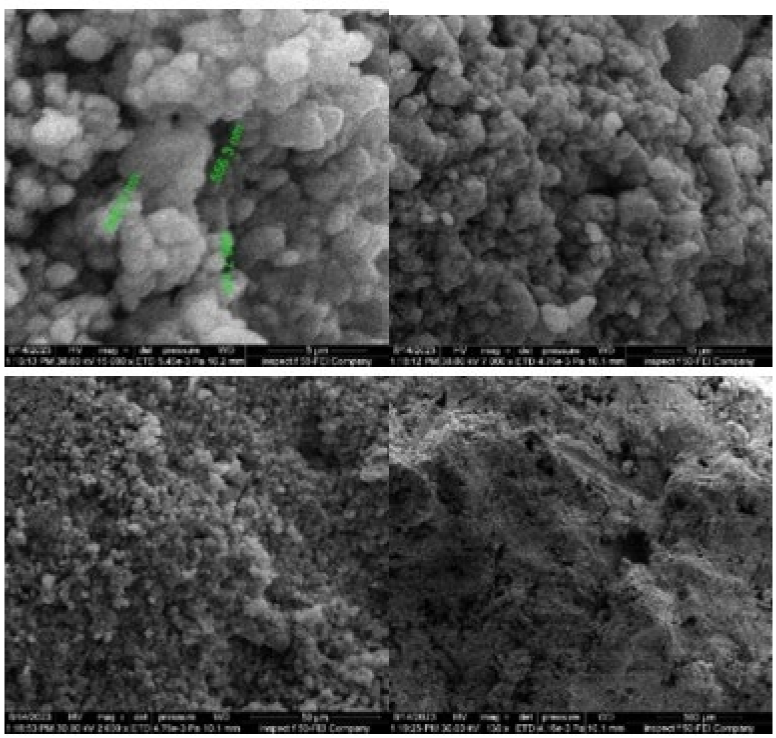

Figure 4. Thin section image for KH section.

### 2.3. EDS

The results of this test analysis gives the mineral content of the studied slices. This test provides weight percent mineralogy. The stress-dependent behavior of rocks is influenced by their mineral composition due to the mechanical characteristics of ductility and brittleness [10] the results of the tested samples are illustrated in Table 1 and Table 2.

Table 1. Mineralogy test results of KH sample.

| | C | O | Mg | Al | Si | S | Ca | Ni |
|---|---|---|---|---|---|---|---|---|
| Atomic % | 38.1 | 55.9 | 0.3 | 0.1 | 0.1 | 0.1 | 5.3 | 0.0 |
| Atomic % error | 0.3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Weight % | 28.8 | 56.4 | 0.5 | 0.1 | 0.3 | 0.3 | 13.4 | 0.2 |
| Weight % error | 0.3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 |

Table 2. Mineralogy test results of T formation.

| | C | O | Mg | Al | Si | S | Cl | Ca |
|---|---|---|---|---|---|---|---|---|
| Atomic % | 44.6 | 50.5 | 0.2 | 0.1 | 0.2 | 0.1 | 0.0 | 4.4 |
| Atomic % error | 0.4 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Weight % | 34.9 | 52.6 | 0.3 | 0.1 | 0.3 | 0.1 | 0.1 | 11.6 |
| Weight % error | 0.3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |

## 3. Mechanical rock properties

Estimation of mechanical rock properties is a very important parameter in applications related to reservoir geomechanics, including proper drilling, and production programs, prediction of fractures, wellbore instability, and other engineering techniques. Usually, the mechanical rock properties are calculated by using the static method and dynamic method. Dynamic methods usually depend on well logs. Static methods are conducted in the laboratory with experimental equipment that contains a core sample. These properties are significant for the construction of the mechanical earth model (MEM). The mechanical properties of the rocks contain strength properties and elastic liner. The rock's elastic mechanical properties include Young's modulus, Poisson's ratio, shear modulus, and bulk modulus. The mechanical properties can be estimated by performing several static rock tests or can be obtained using well logs such as density and sonic log data. The dynamic measurement covers the shear and compression slowness of the sonic log. Usually, dynamic measurement is exceeding static once. Therefore, in anisotropic materials, the elastic modulus does not have unique values, but in isotropic the elastic rock properties have the same values in a plane for all directions [11]. Young's modulus describes the elastic properties of a solid under compression and tension in a single direction. The mathematical equation for Young's modulus is According to Hook's law, the mathematical equation of Young's modulus is the ratio of lengthwise stresses ($\sigma x$) to the longitudinal strain ($\varepsilon x$).

In this study, the correlation used to estimate Young's modulus is presented by the following equation [19].

$$E = \frac{3}{4}G + K_b \qquad (1)$$

where: G, the shear modulus is the ratio of the shear load to the lateral displacement; bulk modulus Kb indicates bulk compressibility, and it is influenced by the formation fluids and solids compressibility.

$$G = \frac{\mathrm{A\rho b}}{\mathrm{tc2}} \qquad (2)$$

where A = 1−2

$$E = \frac{3}{4}\mathrm{G} + \mathrm{K_b} \qquad (3)$$

Poisson's ratio (v) is an essential property in rock mechanics since it represents the ratio of lateral deformation to vertical extension under longitudinal tensile stress [12]

$$\frac{v}{1-v} = \frac{G_f - G_p}{G_{ov} - G_p} \ \ldots \qquad (4)$$

Other correlation used to compute strength modulus as follows:

$$v = \frac{3K_b - 2G}{6K_b + 2G} \ \ldots \qquad (5)$$

The strength is the rock's ability to withstand an applied weight before failure. The relationship between the applied external loads of material and the resulting changes in the rock dimensions depends on the strength of that material [13]. The strength characteristics play an important role in rock mechanics for applications related to reservoir geomechanics and it is with respect to the rock compressive strength, shear strength, and tensile strength [14].

$UCS = 0.008EV_{cl} + 0.0045E(1 - V_{cl})$ (6)

$UCS=9.95V_P^{1.21}$ (7)

Tensile strength is the greatest tension that a rock can withstand before failing, and if this limit is exceeded by the effective tensile stresses, it will fail and that leads to a fracture that splits the rock. The rocks contain small cracks predominantly; these original cracks are the cause of the fracture rocks after tensile failure. This means the existence of cracks helps to tensile failure after reaching the maximum stress. Hence, the rock's tensile strength is very small and may approach zero when cracks occur naturally with respect to the tensile load [14]. The tensile strength in the study was determined using the equation below.

$Ti = \frac{0.025UCS}{10^6 C_B} \ldots$ (8)

where Ti is the rock's tensile strength.

## 4. Mechanical earth model

In the application of rock mechanics, rock failure criterion is one of the most important issues that must be checked during drilling operations to know the condition of the rocks, prevent malfunctions in drilled rock structures, and help to predict the direction of hydraulic fracture. Many failure criteria were developed to estimate rock failure, such as the Mohr-Coulomb and Hoek-Brown parameters, which do not consider intermediate principal stress, while Modified Lade and Mogi Coulomb take into consideration the intermediate principal stress and its effect on rock failure [1]. The basic failure criteria of a vertical well, that is the tensile breakdown pressure under the failure criterion creates an axial fracture. Also, he applies the same failure criteria for a horizontal well and depending on the relative values of stresses because vertical stress is usually the largest of the three stresses. The failure criteria proposed by Hubert and Willis are valid for both vertical and horizontal wells, but they assume the creation of axial fracture (longitudinal) only because of a tensile failure of the rock. For adequate detection of candidate layer selected for adjusting hydraulic fracturing operation, four deviated wells are considering in the current study for accurate evaluation of different stress values using Techlog software. The required data for construct 1D MEM pertinent are; Bulk density, sonic log (compression and shear), porosity and Gamma ray. The calculating process and output results for the investigated four wells are described briefly in this section.

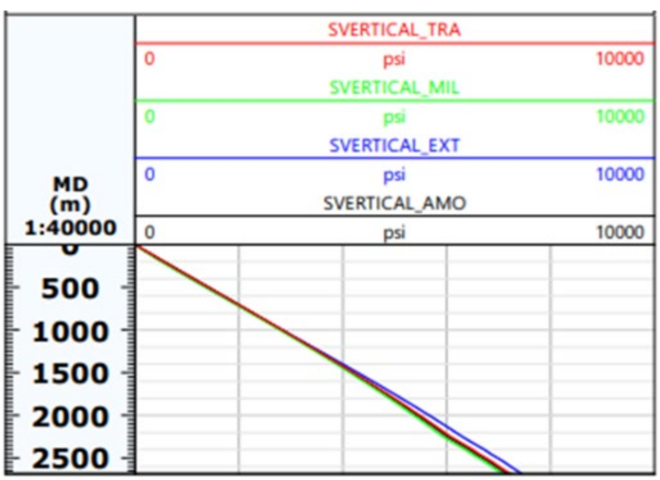


Figure 5. Comparison between overburden pressure methods

**A. Vertical stress** (referred to as overburden stress or lithostatic pressure) is fundamentally attributed to the weight of both overlaying formations and the fluid they confined [15] . In this study, four methods were used which are: Extrapolated Density, Amoco Empirical Relation, Gardner Density from Sonic or Seismic Data, and Miller Density method as shown in Figure 5.

A comparison between these four methods results were useful to find the best method describe real estimation of vertical stress. The results were very similar between the four methods as shown in Figure 5 therefore, Miller method was chosen based on its useful parameters as shown in the following equations.

$$\rho_{extrapolated} = \rho_{mudline} + A_o(TVD - Air\ Gap)^a \quad (12)$$

where: $\rho mudline$ is the density at ground level (1.65 gm/cc); TVD is the true vertical depth; Air Gap: is Rig floor height from the ground level; ($Ao$ & ɑ) are fitting parameters.

$$\emptyset_{Miller} = \emptyset_a + \emptyset_b e^{(-k*(TVD-AirGap-WaterDepth)} \quad (13)$$

**B. Pore pressure** is an important geomechanical model that uses essential in-situ stresses (principal stresses around the wellbore and in the far field reservoir), effective stress, and designed mud windows for wellbore instability [16]. The pore pressure of formations with a hydrostatic gradient is referred to as the normal pore pressure. Normal pore pressure indicates an interconnected column of formation fluid that extends from the surface to the depth of interest and increases steadily with depth based on the density of the formation-contained fluid [17]. Pore pressure was calculated using the Eaton method and sonic log data for the studied four wells.

**C. Geomechanical properties** log data are used to determine and analyze rock dynamic mechanical properties, including the Young modulus E, shear modulus G, and Poisson's ratio ʋ. Equations (2) and (3) are used to calculate E and G. The calculation results are depicted in the Figures 6, 7 ,8 and 9 for each well.

**D. Horizontal stress** affect horizontal stresses. It is produced from vertical stresses on a specific point, and usually, these stresses are equal. Plate tectonic motions are the main contributors to changes in horizontal stresses. Horizontal stresses are classified into a minimum ($\sigma h$) and a maximum($\sigma H$), horizontal stress σh are determined for each well using Eq. (14 and 15) [18- 20].

$$\sigma h = \frac{v}{1-v}\sigma v - \frac{v}{1-v}\alpha P_p + \alpha p_p + \frac{V}{1-V^2}\varepsilon_X + \frac{Ev}{1-v^2}\varepsilon_y \quad (14)$$

$$\sigma_H = \frac{v}{1-v}\sigma v - \frac{v}{1-v}\alpha P_p + \alpha p_p + \frac{Ev}{1-V^2}\varepsilon_X + \frac{E}{1-v^2}\varepsilon_y \quad (15)$$

## 5. Suitable layer selection

Hydraulic fracturing operation of wells is one of the most effective techniques in developing tight reservoirs. Inappropriate intervals selection may cause high breakdown pressures or failed to breakdown the formation and consequently poor placement of wells or poor initialization and propagation of hydraulic fractures. Many parameters are known to be important to determine the suitable layer for locating Hydraulic fracturing. The important parameters are represented by two parts, the first part is the geomechanical properties such as low in situ stress, low Young's modulus, low UCS and low Poisson ratio, the second part consists of the petrophysical properties such as high porosity, high permeability and low water saturation. Together, these specifications help in selecting the hydraulic fracture location. While in some layers there is an increase in the YM and a PR, which represents a barrier layer. Where UCS is weaker it means that rock has low level of strength and fracture Formation is easier and vice versa. In other words, high UCS not only restricts fracture Initiation but also makes some problems on the way to identify the suitable layer for hydraulic fracturing operation [21-22].

Table 3. Choice optimum layer in each formation depend on geotechnical properties

| Name wells | Formation | Depth(m) | Young’s modulus(Mpsi) | Poisson’s ratio | UCS (psi) |
|---|---|---|---|---|---|
| Well A | S | 2179 | 0.735 | 0.178 | 3118 |
| | T | 2328 | 0.68 | 0.19 | 2923 |
| | KH | 2475 | 0.66 | 0.17 | 2815 |
| Well B | S | 2238 | 0.87 | 0.28 | 3706 |
| | T | 2422 | 0.64 | 0.287 | 2722 |
| | KH | 2564 | 0.66 | 0.288 | 2812 |
| Well C | S | 2230 | 1.08 | 0.233 | 4599 |
| | T | 2360 | 0.85 | 0.232 | 3617 |
| | KH | 2473 | 0.97 | 0.231 | 4137 |
| Well D | S | 2230 | 0.92 | 0.116 | 3918 |
| | T | 2344 | 0.52 | 0.117 | 2523 |
| | KH | 2465 | 0.7 | 0.116 | 2977 |

In the current study to select a suitable layer to create a fracture in each well for S ,T and KH formations at which the mechanical properties (Young's modulus, Poisson's ratio and unconfined compressive strength ) are low-value illustrated in Table 3 the depth location to create a hydraulic fracture .

## 6. Results and discussion

Using a mechanical earth model is of great importance to predict the magnitude of well pressures and geomechanical properties, as they greatly affect the selection of the appropriate layer for hydraulic fracturing design operations. In this research, studied of four wells A, B, C and D, and they consist of three formations S, T and Kh. The thickness of the S, T and Kh formations respectively is 146 m,116 m and 125 in well A , in well B the thickness 160m, 137m and 155m in well B, in well C the thickness is 122m, 110m and 114m and the thickness of well D is 115m, 102m and 113. The thickness of the formations is good, which helps stabilize the hydraulic fracture, reduces the collapse of hydraulic fracture and the good thickness provides a larger surface area for interaction between the fractal fluid and the rock, allowing more oil to be released. created one-dimensional mechanical earth modeling for the studied wells as shown in Figures 6, 7, 8 and 9. As for the unconfined compressive strength (UCS), as one of the main parameters in the geomechanics of reservoirs, it represents the strength of the rocks that can withstand the applied pressure. Table 4 shows the measured value of UCS, where the S formation shows a high bearing strength, which means is a need to apply a great compressive strength, to creating a hydraulic fracture. while in the T and KH formations was lower value of UCS in many layers, as in the Figures 6, 7, 8 and 9, this is considered a good indicator for creating a fracture.

Table 4. Results of rock mechanical properties.

| Parameters | Reservoir | Well name A | B | C | D |
|---|---|---|---|---|---|
| Young's modulus (Mpsi) | S | 0.9 – 3.2 | 0.9 – 2.18 | 1.15 – 2.7 | 0.94 – 2.37 |
| | T | 0.8 – 4.1 | 0.6 – 9.94 | 0.97 – 3.7 | 0.6 – 2.9 |
| | KH | 0.75 – 6.4 | 0.7 – 2.2 | 0.93 – 2.7 | 0.7 – 3.8 |
| Poisson ratio | S | 0.17 – 0.18 | 0.286 – 0.289 | 0.23 – 0.235 | 0.114 – 0.117 |
| | T | 0.18 – 0.23 | 0.283 – 0.285 | 0.231 – 0.234 | 0.115 – 0.118 |
| | KH | 0.16 – 0.19 | 0.285 – 0.289 | 0.233 – 0.236 | 0.112 – 0.117 |
| UCS | S | 2935 –10767 | 3957 – 9374 | 4551 – 8305 | 3939 – 8717 |
| | T | 2860 –11455 | 2737 – 6488 | 3780 –13216 | 2523 –12312 |
| | KH | 2958 – 21094 | 2765 –10154 | 3878 –7623 | 3086 – 20055 |

SEM image provides a structural explanation for the sample's behavior. many samples that show a normal trend in the permeability-stress relationship in the T/KH reservoir. The layer appears low sensitivity of these core samples to stress as illustrated in Figures. 2, 3, and 4 describing SEM and TS test.

High rock porosity can affect the resulted value of Poisson ratio caused by a vuggy pore partially filled with sparry calcite in the studied core samples. The results of Figures 6 ,7 ,8 and 9 also revealed that the friction angle for the reservoir under study as explained in Table 5 are within the range of carbonate reservoirs [18].

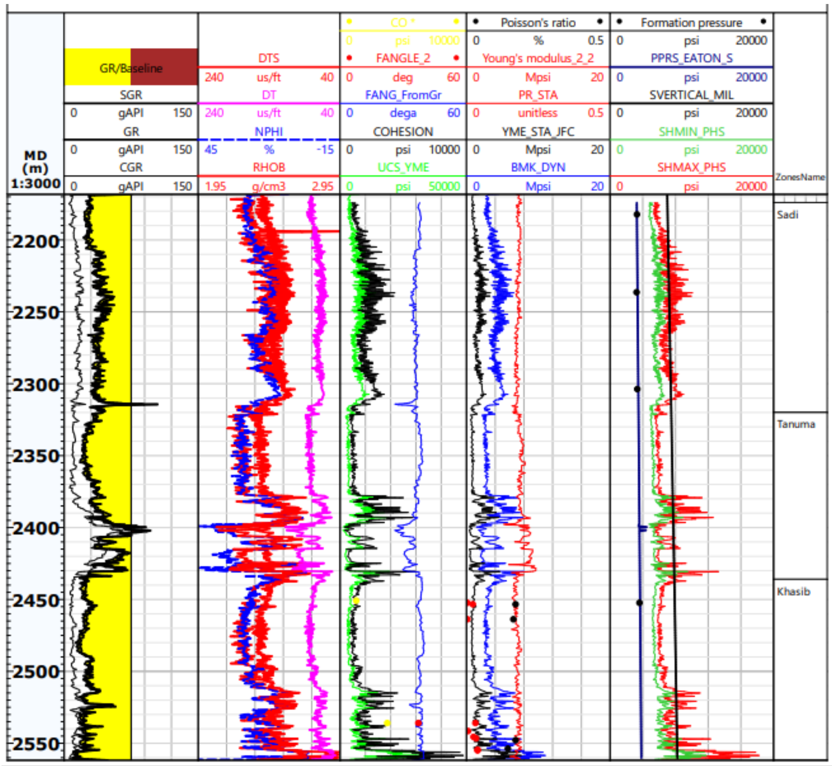

Figure 6. Calculated mechanical earth model (MEM) for the well A.

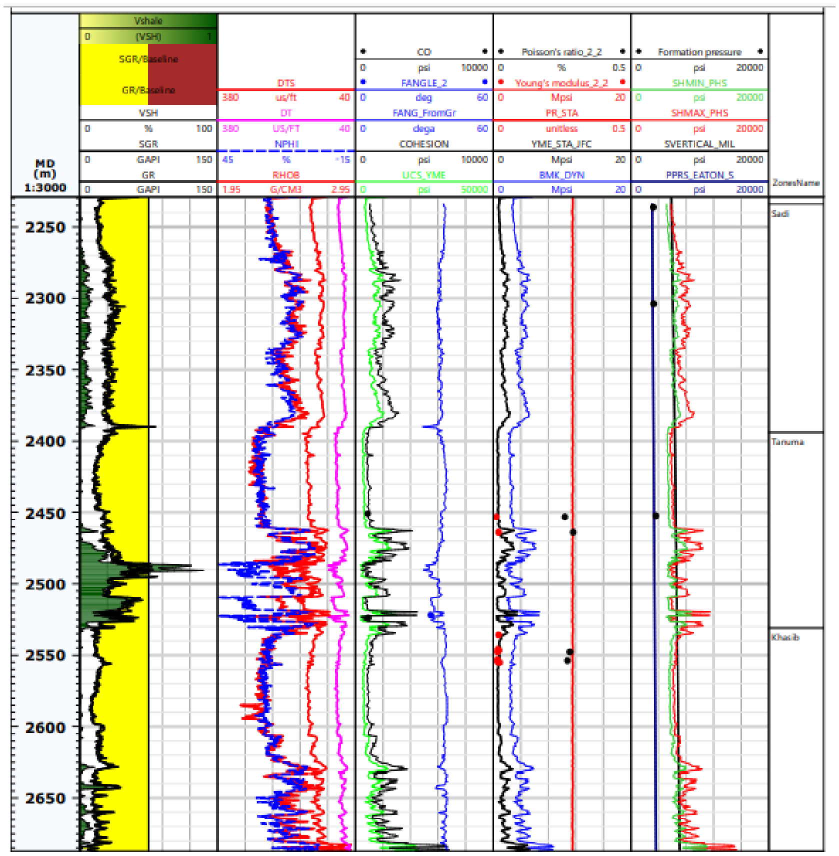

Figure 7. Calculated mechanical earth model (MEM) for the well B.

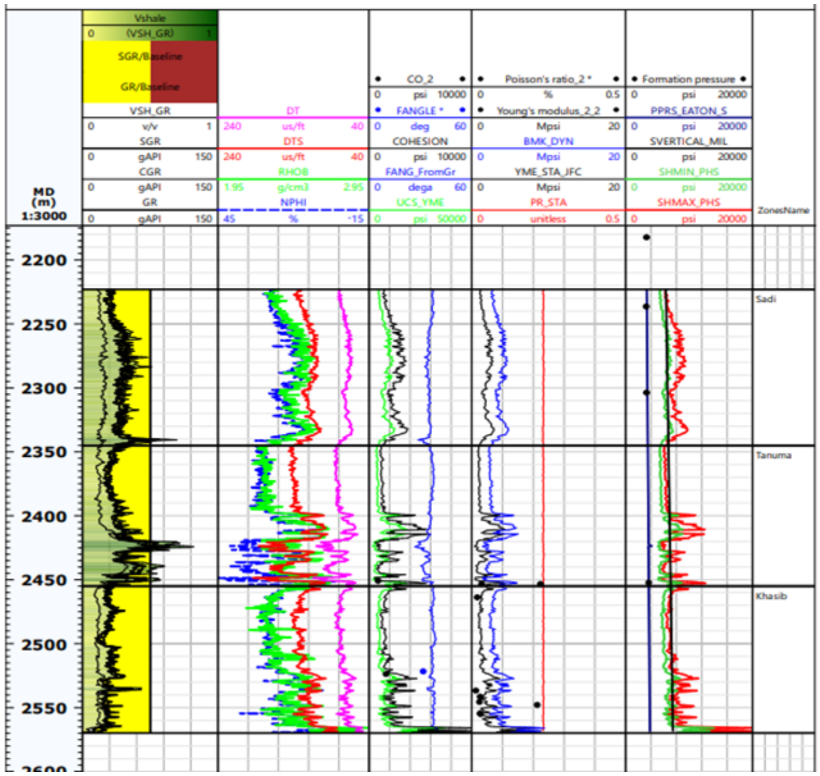

Figure 8. Calculated mechanical earth model (MEM) for the well C.

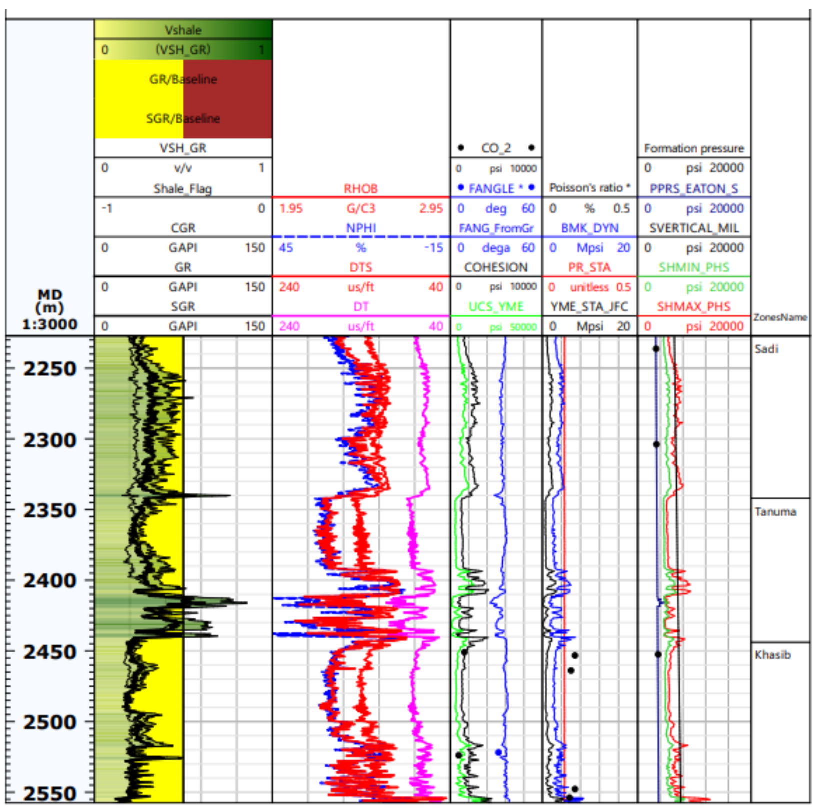

Figure 9. Calculated mechanical earth model (MEM) for the well D.

Table 5. Results of friction angle and cohesion from MEM

| Parameters | Well name | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Cohesion(psi) | 724-6376 | 906-2077 | 1264 | 1722-3931 |
| Friction angle(deg) | 30-38 | 34-39 | 29-37 | 1722-3931 |

## 7. Conclusions

The present study concern on suitable layer selection for conducting a hydraulic fracturing job based on experimental evaluation of core samples and geomechanical evaluation. The most critical factors effect on best layers selection as indicated from 1-D MEM are Young modulus E and the rock compressive strength UCS. Also, horizontal stresses are a crucial parameter for best layer selection due to its effect on the resulted fractures direction. Close analysis of SEM and TS test of the core samples indicate that the studied layers show low sensitive to stress. SEM and Ts test are valuable in mechanical properties analysis. High rock porosity indicated as vuggy pore partially filled with sparry calcite can affect the resulted value of Poisson ratio as shown in the studied core samples.

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*To whom correspondence should be addressed: Amani Ihsan, Department of Petroleum Engineering, College of Engineering, University of Baghdad, Iraq, E-mail: amani.ihsan2308m@coeng.uobaghdad.edu.iq*