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Predicting Rock Mechanical Properties from Wireline Logs in Rumaila Oilfield, Southern Iraq

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Abstract

Rock mechanical properties that include compressive strength, shear strength, cohesion and internal friction angle are important elements in any Geomechanical study that aims to maintain wellbore stability and reduce non-productive time (NPT) during drilling new wells in any oil or gas field. The main goal of this study is to estimate the values of rock strength for the Geological column of Rumaila oilfield using well log data. The values of rock mechanical properties were measured directly throughout laboratory tests (Uniaxial and triaxial tests) on core samples obtained from wells A, B, C and estimated indirectly using well log data (gamma ray, density, sonic (compressional and shear), and Neutron logs) from eight wells (A, B, C, D, E, F, G and H), covering the geological column starting from Sadi to bottom of Zubair Formation in Rumaila oilfield, the results showed similarity to the direct measurements that been obtained from uniaxial and triaxial mechanical laboratory tests which make it reliable method for continuous measurements of rock strength and can be used for wellbore stability analysis or any other Geomechanical study.

Keywords

Rock Compressive, Shear Strength, Internal Friction Angle, Cohesion

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1. Introduction

Knowledge of rock strength is a necessary element in analysis and modeling of earth stress, borehole stability during drilling, sand production and hydraulic fracturing. Rock strength is defined as the peak of stress reached when rock begins deforming throughout a compress test. Determination of rock strength and failure features could be carried out by two main methods: static and dynamic. Static methods are mostly laboratory tests that carried out by special equipment using core sample for measuring its mechanical properties. Dynamic methods are usually calculations of velocity of compressional wave (V_P) and velocity of shear wave (V_S), which can be acquired from logs; velocity is simply the inverse of slowness (Δ t). The best representative of the actual rock strength behavior is the mechanical tests, but, acquiring this data is expensive and time consuming because these approaches involve extracting formation core samples, and merely symbolize the properties of rock at that precise position [1]. Hence, both laboratory experiments and well logs methods are needed for of rock mechanical properties measurements [2].

2. Rock Compressive Strength

This property describes the rock limit of loading and its plastic act also predicts rock mechanical shear strength, tensile strength and uniaxial compressive strength [3].

2.1. Rock Compressive Strength from Laboratory Tests

The two most wide spread laboratory techniques that used for measuring rock compressive strength are the uniaxial test and triaxial test. The results of the laboratory tests can be used later to calibrate the values of rock strength obtained from log data [4].

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Rock mechanical compressive strength characterization tests in Rumaila oilfield were accomplished on core plugs taken from Zubair Formation in wells B, C and from Sadi, Mishrif, Ahmadi, Nahr Umr and Zubair formations in well A. Laboratory tests included unconfined compressive strength (UCS) and triaxial compression strength testing (TCS). Table 1. summarize the results of uniaxial compression test (UCS) on core plugs in wells A, b and c, these tests were accomplished in FracTech Laboratories [5].

Table 1. Uniaxial compression test results in wells A, B and C [5].

Well	Core depth (m)	Formation	Rock Type	Test type	UCS (psi)
A	2459.14	Ahmadi	Limestone	UCS	21039
A	2731.95	Nahr Umr	Sandstone	UCS	9873
A	2748.08	Nahr Umr	Shale	UCS	16088
A	3077.97	Zubair	Sandstone	UCS	11478
B	3242.11	Zubair	Sandstone	UCS	6934
B	3246.45	Zubair	Sandstone	UCS	4166
B	3259.11	Zubair	Sandstone	UCS	4737
B	3274.29	Zubair	Sandstone	UCS	10570
C	3175.53	Zubair	Sandstone	UCS	3267
C	3192.82	Zubair	Sandstone	UCS	4137

2.2. Rock Compressive Strength from Logs

Rock compressive strength can be estimated indirectly by employing log data, this procedure advantages include lower cost, logging data availability and continued prediction of mechanical features of rocks per depth [6]. There are different procedures that have been developed to determine rock strength from well log parameters [3].

Rock compressive strength is influenced by rock properties for instance grain size, porosity, cement, texture, fluid content and degree of compaction. Employing the effect of porosity in rock strength prediction is important to accomplish more accuracy in the calculations. Wherefore, equation (1) was introduced to designate best relationship between UCS, porosity and sonic travel time by employing neutron and sonic travel time log data [7].

$$UCS = 194.4 - 0.6072\Delta t - 646.1\varphi - 0.01644\Delta t^2 + 8.792(\varphi.\Delta t) \quad (1)$$

Where:

UCS is unconfined compressive strength in Mpa (1 Mpa=145 psi).

Δ t: Sonic travel time (µsec/ft).

φ: Neutron log porosity (NPHI) in (fraction).

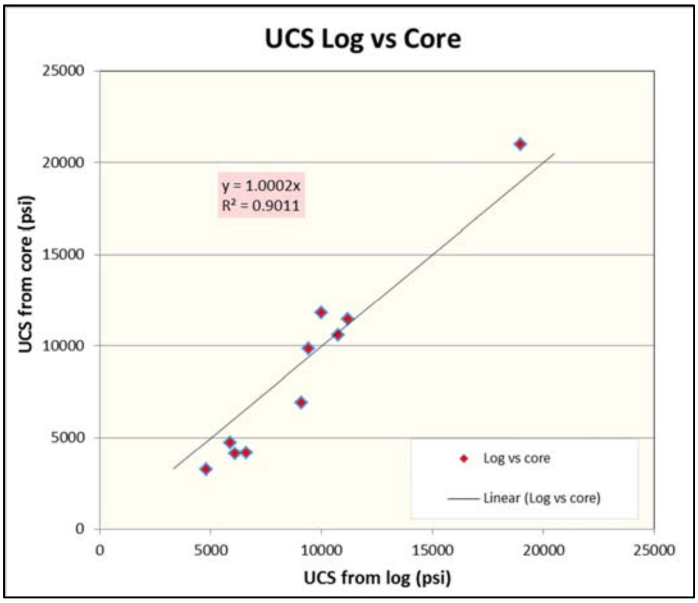

Figure 1. Comparison between UCS values calculated from logs and laboratory tests.

Figure 1 demonstrates a comparison between UCS values obtained indirectly by logs using equation (1) and directly by core tests for the wells A, B and C, that comparison indicated that logs had provided a good estimation of UCS as the match between direct and indirect method was 90%.

3. Rock Shear Strength

The shear strength of a rock is the maximum shear resistance a rock is able to develop. Two elements comprise shear strength that are the particles friction angle and Cohesion [8]. Internal friction angle ( ) is an amount of the capability of a rock unit to endure a shear stress. Thus it is commonly used with unconfined compressive strength (UCS) to estimate rock strength. It is represented as the angle that takes place between the typical force and resulting force once a shear stress caused a failure; and it can be estimates by a triaxial shear test in laboratory. The higher the friction angle, the greater the rate of increase of strength with confining stress [9]. Cohesion can be represented as the molecular attraction or bonding among rock grains. It had a relation with moisture content, mineralogy of Clay, density and orientation of particles. Cohesion had a correspondence with Clays and Silts (fine grain rocks) [10].

3.1. Internal Friction Angle from Laboratory Tests

Values of internal friction angle (ϕ) attained from laboratory tests on core samples were accomplished through subjecting nine core plug samples to triaxial test. These samples were taken from Sadi, Ahmadi, and Zubair formations in well A in Rumaila oilfield, the resultant values of internal friction angle are demonstrated in Table 2.

Table 2. Internal friction angle values from triaxial compression test on well A.

Core depth (m)	Formation	Rock Type	Friction Angle (deg)
2140.47	Sadi	Limestone	33.6
2140.03	Sadi	Limestone	34.8
2143.85	Sadi	Limestone	41.8
2143.93	Sadi	Limestone	32.4
2147.43	Sadi	Limestone	31.8
2147.39	Sadi	Limestone	32
2459.21	Ahmadi	Limestone	61.5
3077.92	Zubair/Upper shale	Limestone	40
3077.97	Zubair/Upper shale	Limestone	31.5

3.2. Internal Friction Angle from Logs

It is feasible to develop a clear empirical relationship between Gamma ray log and internal friction angle, this technique maps gamma ray to friction angle with a linear correlation [11]. A linear correlation between friction angles acquired from lab test with their correspondent gamma ray values obtained from wireline log (Figure 2), this correlation incorporated lab test data and logs from well A in Rumaila oilfield.

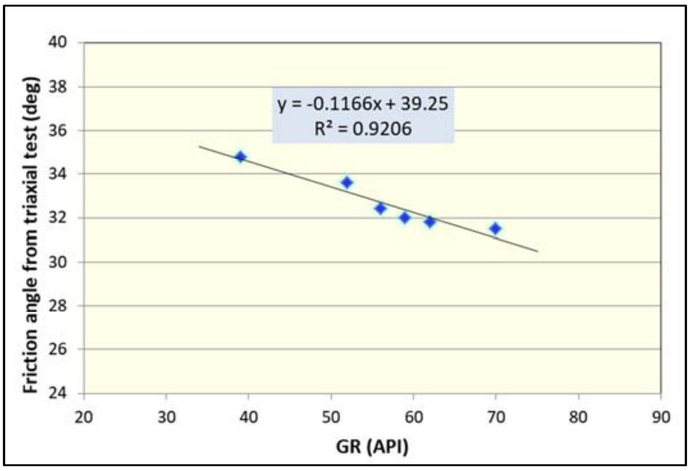

Figure 1. Empirical relation between gamma ray log and friction angle.

The resultant empirical relationship that determines values of friction angle from gamma ray as explained in Figure 2 can be stated as:

$$\phi = (-0.1166 * GR) + 39.25 \qquad (2)$$

Where:

: The internal friction angle (degree).

GR: Gamma ray log reading (API).

The above relationship declares that with increasing GR in Shaly rock the friction angle tends to decrease. To be within friction angle limits, a cutoff was applied to friction angle, if the calculated friction angle is less than 15 deg; it is forced to 15 deg. If it is greater than 40 deg, it is forced to 40 deg [12].

4. Cohesion

Rock cohesion (S_0) can be computed as a function of UCS and friction angle as following [13, 14]:

$$S_0 = \frac{UCS}{2*\left[\left(\sqrt{(1+(\tan\phi)^2}\right)+\tan\phi\right]} \quad (3)$$

Where:

S_o is rock cohesion (psi).

ϕ: Angle of internal friction (degree).

UCS: The unconfined compressive strength (psi).

Resultant values of UCS, Friction angle and Cohesion are demonstrated from Figure 3 to Figure 7 for the wells D, E, F, G and H in Rumaila oilfield.

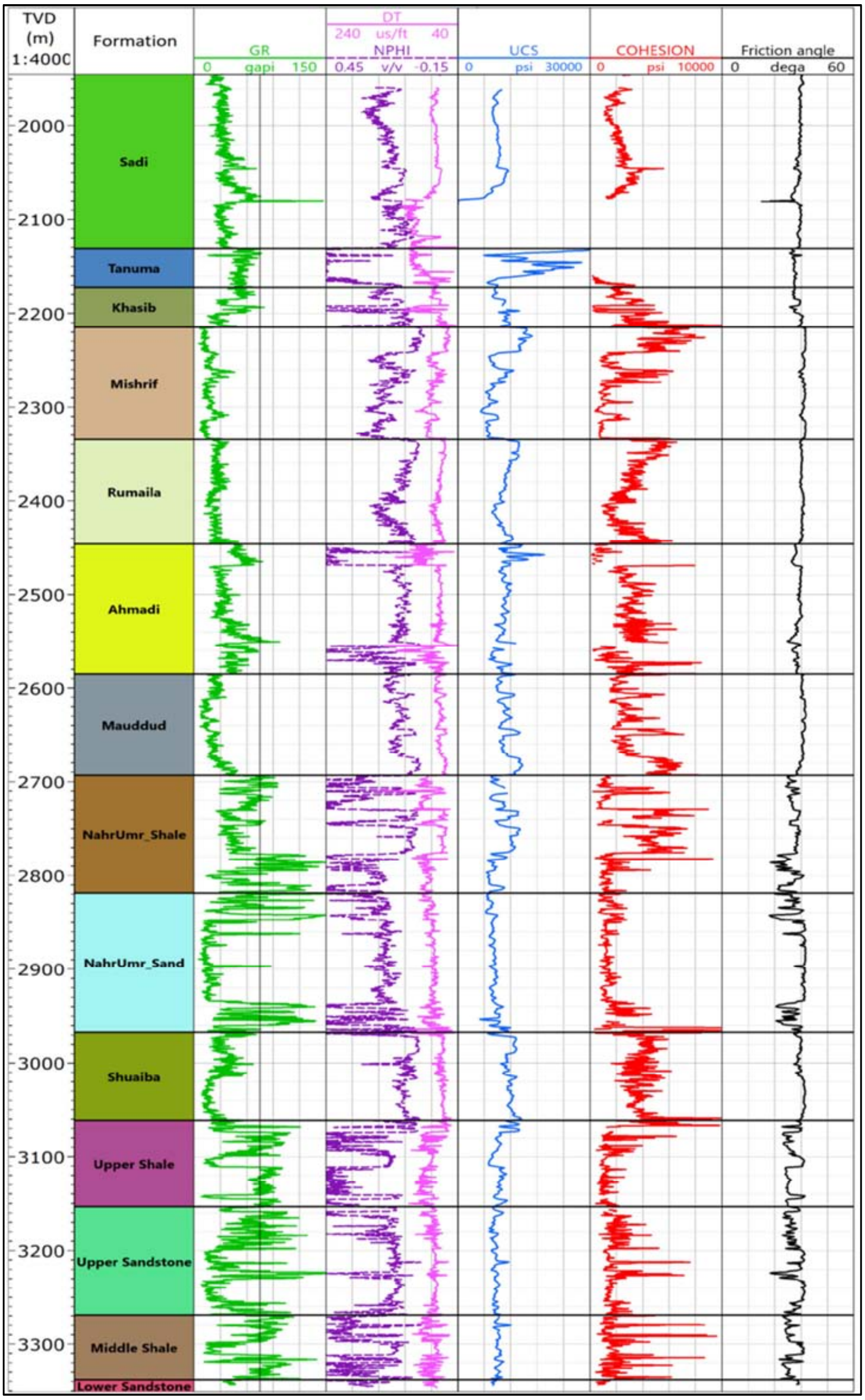

Figure 2. Values of rock strength (UCS), Friction angle and Cohesion in well D.

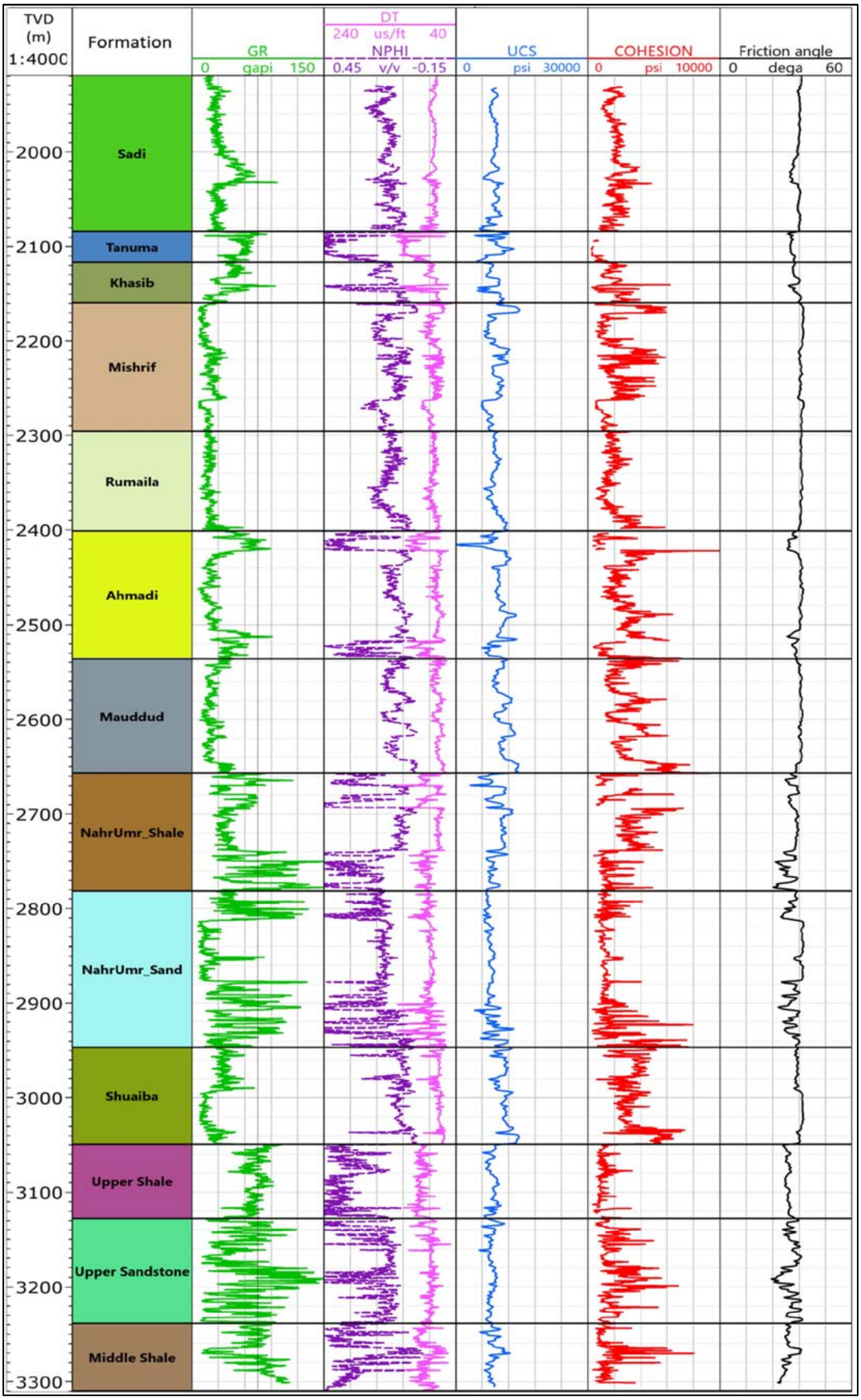

Figure 3. Values of rock strength (UCS), Friction angle and Cohesion in well E.

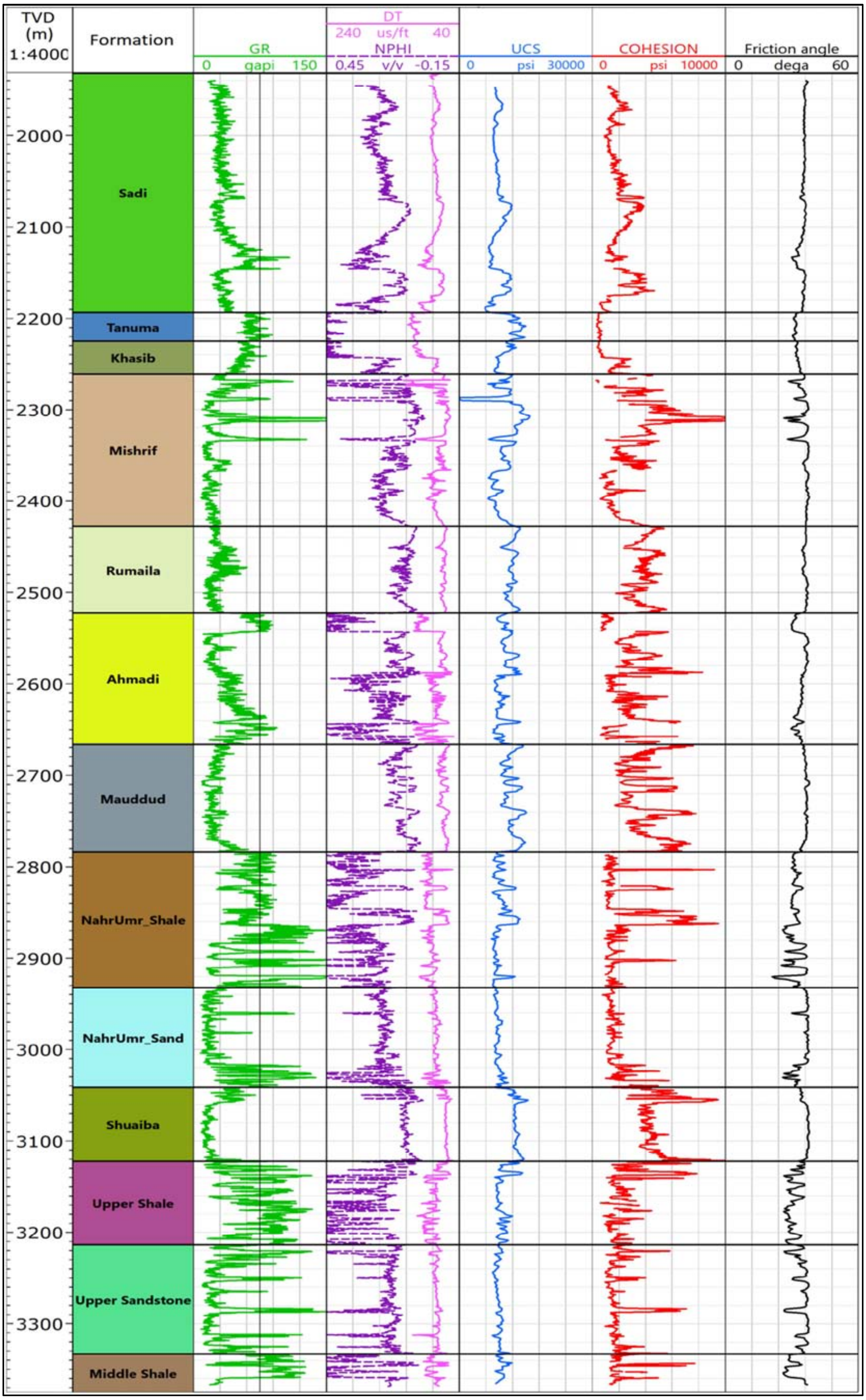

Figure 4. Values of rock strength (UCS), Friction angle and Cohesion in well F.

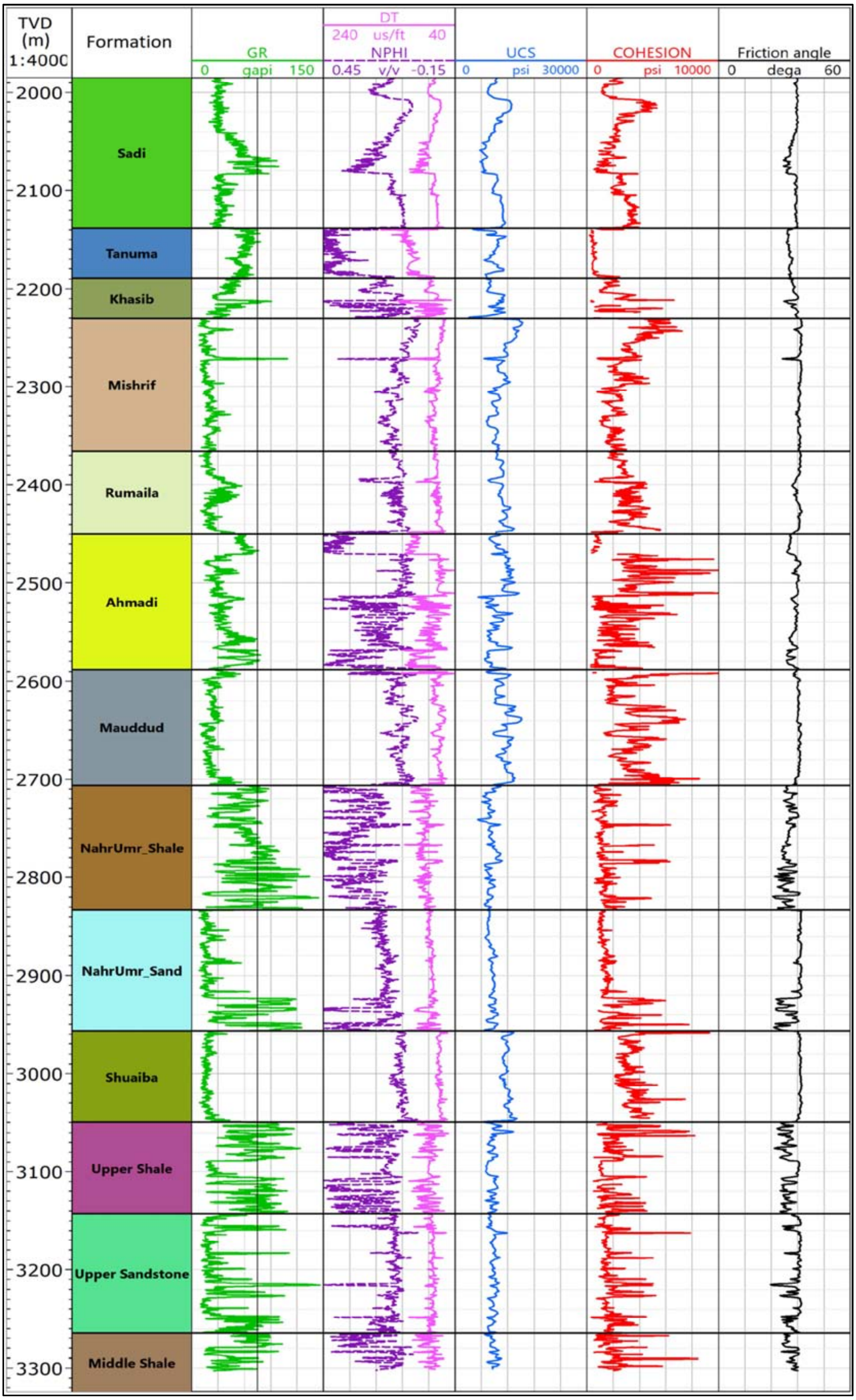

Figure 6. Values of rock strength (UCS), Friction angle and Cohesion in well G.

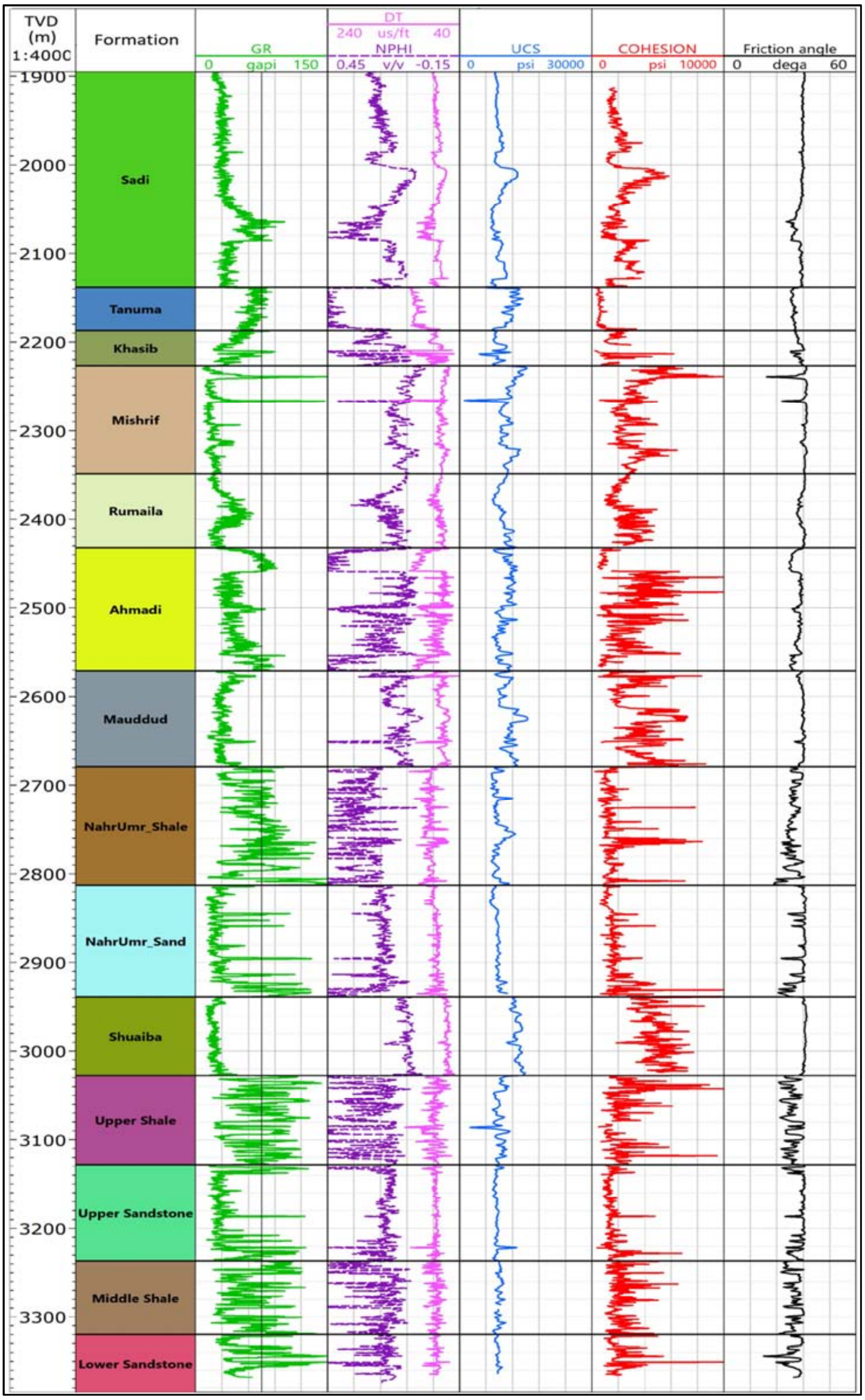

Figure 7. Values of rock strength (UCS), Friction angle and Cohesion in well H.

5. Discussion

Results of estimated values of rock compressive and shear strength are presented in figures 3 to 7.

There is an increase in the values of unconfined compressive strength (UCS) with depth for each individual formation due to increase of the overlying rocks and fluids load, it is also noted that UCS values for Carbonate rocks (Sadi, Khasib, Rumaila, Ahmadi Mauddud and Shuaiba Formations) are higher than the Clastic rocks (Tanuma, Nahr Umr and Zubair Formations). Shale and Shaly layers have lowest values of Cohesion and friction angle which make it the most prone rock type for failure and collapse during drilling operation, these layers are observed in Tanuma, Ahmadi, Nahr Umr and Zubair Formations.

6. Conclusions

1. Values of rock strength obtained indirectly from wireline logs showed good correlation with the direct measurements from laboratory tests on core samples where the match percentage is about 91%.
2. Wireline logs (Density, sonic and neutron) can be used to predict the values of UCS.
3. Adding the effect of porosity in rock strength prediction is important to accomplish more accuracy in the calculations.
4. Internal friction angle can be estimated by developing an empirical relationship between gamma ray log and measured value measured directly by core analysis.
5. Carbonate Rocks have higher strength values than clastic rocks which make it suitable for bare-foot completion as a substitute of casing completion, Mishrif reservoir is a good candidate for this type of completion which offer higher production rates with less cost.
6. Breakout and washout in Shale and Shaly layers is associated with low cohesion zones.

Nomenclature

Symbol	Definition
UCS	Unconfined compressive strength
Δt	Sonic travel time
φ	Neutron log porosity
ϕ	Internal friction angle
GR	Gamma ray log reading
S_o	Rock cohesion

References

[1] Fjaer, E. (2009). Static and dynamic moduli of a weak sandstone. *Geophysics*, *74* (2), WA103-WA112.

[2] Xu, H., Zhou, W., Xie, R., Da, L., Xiao, C., Shan, Y., & Zhang, H. (2016). Characterization of rock mechanical properties using lab tests and numerical interpretation model of well logs. *Mathematical Problems in Engineering*, *2016*..

[3] Fjar, E., Holt, R. M., Raaen, A. M., Risnes, R., & Horsrud, P. (2008). *Petroleum related rock mechanics* (Vol. 53). Elsevier.

[4] Cook, J., Frederiksen, R. A., Hasbo, K., Green, S., Judzis, A., Martin, J. W.,... & Noeth, S. (2007). Rocks matter: Ground truth in geomechanics. *Oilfield review*, *19* (3), 36-55.

[5] Rumaila Operating Organization ROO. “Rock mechanical strength characterization of core”. Iraq, 2014.

[6] Franquet, J. A. (2007), Log-based Geo-mechanical Characterization for Open hole Stability Analysis of Horizontal Wellbores, *1st SPWLA India Regional Conference*.

[7] Amani, A., and Shahbazi, K. (2013). Prediction of rock strength using drilling data and sonic logs. *International Journal of Computer Applications* 81, no. 2.

[8] Amadei, B., Stephansson, O. (1997). *Rock stress and its measurement*. Springer Science & Business Media.

[9] Aadnoy, B., & Looyeh, R. (2019). *Petroleum rock mechanics: drilling operations and well design*. Gulf Professional Publishing.

[10] Fabio Vittorio De Blasio, (2011), *Introduction to the physics of landslides: lecture notes on the dynamics of mass wasting*. Springer Science & Business Media.

[11] Moos, D. (2006). *Geomechanics applied to drilling engineering*. Petroleum engineering handbook, 2.

[12] Schlumberger Limited, (2015), Techlog 2015.3: User Guide. Schlumberger software.

[13] Jaeger, J. C., Cook, N. G., and Zimmerman, R. (2007). Fundamentals of rock mechanics. John Wiley and Sons. Chicago.

[14] Zhang, J., and Yin, S. (2017). Real-Time Pore Pressure Detection: Indicators and Improved Methods. Geofluids, 2017.