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Identification of Natural Fractures in Reservoirs Using Drilling Parameter Models

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Summary

The identification of fracture zones in naturally fractured reservoirs is a challange in unconventional reservoirs. The D-Series software was developed to estimate geomechanical properties of reservoir rocks, such as confined and unconfined compressive strength and Youngs's modulus from drilling data. Drilling data from horizontall wells in North America were used to calculate depth based rock strength and Young's modulus values. From these logs possible natural fractures and fracture zones intersecting the well are identified and verified with corresponding mud losses in these naturally fractured formations. The identification of natural fractures and fracture zones can be used to optimize the completions and stimulation treatments.

Introduction

Researchers and engineers have been investigating convenient and cost effective techniques to obtain continuous rock properties along the wellbore and to characterize natural fractues in reservoirs. The conventional techniques involve core analysis and well logging using sonic and resistivity image logs. These techniques are in many cases expensive, uncertain and sometimes difficult to process . A convenient ROP model was developed to estimate rock properties such as, confined compressive strength (CCS), unconfined compressive strength (UCS) and Young's modulus (E) at each drilled depth penetrated from available drilling data (Hareland et al. 2007 and Hareland et al 2010). The D-Rock software uses the inverted ROP model to estimate rock properties along the well.

In this paper two D-Series software are used to estimate a rock strength log as illustrated in Fig. 1. D-WOB software calculates effective downhole weight on bit (DWOB) from drilling data, drill string information and wellbore survey measurement. D-Rock software estimates the geomechanical rock properties such as, CCS, UCS and Young's modulus (E) using the output from D-WOB software along with drill bit information, mud data and formation lithogy. The possible fractues and fracture zones are identified from the weaker rock strengths (UCS) by monitoring the strength log at each drilled depth and verified with the corresponding mud losses. Drilling fluid or mud losses are common in naturally fractured formations (Majidi et al, 2008).

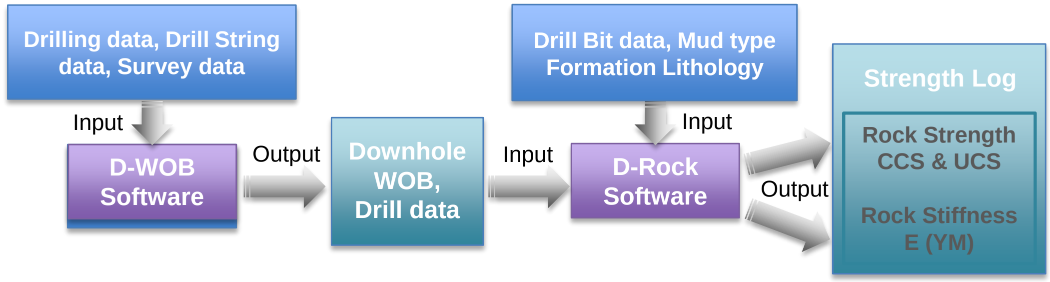


Fig. 1 Overview of D-Series software to estimate rock strength log

Theory and/or Method

The D-WOB software uses wellbore friction models to estimate the coefficient of friction and effective downhole weight on bit (DWOB) from the surface measurement of weight on bit (WOB), hook load along with survey, mud data and drill string information. The model represents the force balance equations on a drill string element either straight or curved, and if the drill string is in tension (Fazalizadeh et al, 2010) or compression (Johancsik et al, 1984). The software estimates coefficient of friction when the drill string is off-bottom. The estimated coefficient of friction is then used to calculate effective DWOB when the drill bit is on-bottom. The D-WOB software calibrates the coefficient of friction during connections for better estimation of downhole DWOB during drilling of horizontal wells.

The force balance equation on a curved drill string element in tension is:

$$F_{top} = \beta w \Delta L \left[\left(\frac{\sin \alpha_{top} - \sin \alpha_{bottom}}{\alpha_{top} - \alpha_{bottom}} \right) + \mu \left(\frac{\cos \alpha_{top} - \cos \alpha_{bot}}{\alpha_{top} - \alpha_{bottom}} \right) \right] + (F_{bottom} - DWOB)\left(e^{-\mu|\theta|}\right) \quad (1)$$

Where, β is buoyancy factor, *w* is the unit weight of drill string element and ΔL is the length of the element. The dogleg angle, θ is the absolute change of direction which depends on both the wellbore inclination, α and azimuth, φ. '*top*' and '*bottom*' represent the top and bottom of the drill string element, respectively.

The output DWOB is applied with other bit parameters to the PDC or Rollercone inverted ROP drill bit model to estimate rock properties used in D-Rock software. In addition, the ROP model also takes into account bit wear, drilling parameters, such as pump flow rate and RPM and drill bit cutting structure (Hareland et al. 2007 and Hareland et al 2010). By inverting and rearranging this convenient ROP model, the rock strength (CCS) can be defined as follows:

$$CCS = f\left(ROP_{field}, DWOB_{estimated}, RPM, W_f, K, h_x\right) \quad (2)$$

where, W_f is bit wear function, K is an empirical constant and h_x is defined as,

$h_x = f(Horsepower\ per\ sq.inch.(HSI), ROP, Bit\ Diameter\ (D_b), Junk\ Slot\ Area\ (JSA))$ for PDC drill bit and, $h_x = f\left(Horsepower\ per\ sq.inch.(HSI), ROP, Bit\ Diameter\ (D_b)\right)$ for Rollercone drill bit.

The corresponding UCS and Young' modulus (E) are defined as,

$$UCS = CCS/\left(1 + a_s \cdot P_c^{b_s}\right) \quad (3)$$

$$E = CCS \cdot a_E \cdot (1 + P_c) b_E \quad (4)$$

Here, P_c is the confining pressure and a_s,b_s,a_E,b_E are constants otained from laboratory triaxial test data for the rock type.

Examples

The D-Series software has used field data from horizontall wells in North America to estimate rock properties and to identify possible fracture zones in naturally fractured reservoirs. The depth-based and 10 second time-based drilling data along with other drilling data are used to obtain the strength log of a horizontal well as shown in Fig. 2. Plot 1 to plot 5 in Fig. 2 represent UCS, CCS, E, ROP and DWOB, respectively from the drilled depth of 1450m to around 1900m in the horizontal section of a horizontal well.

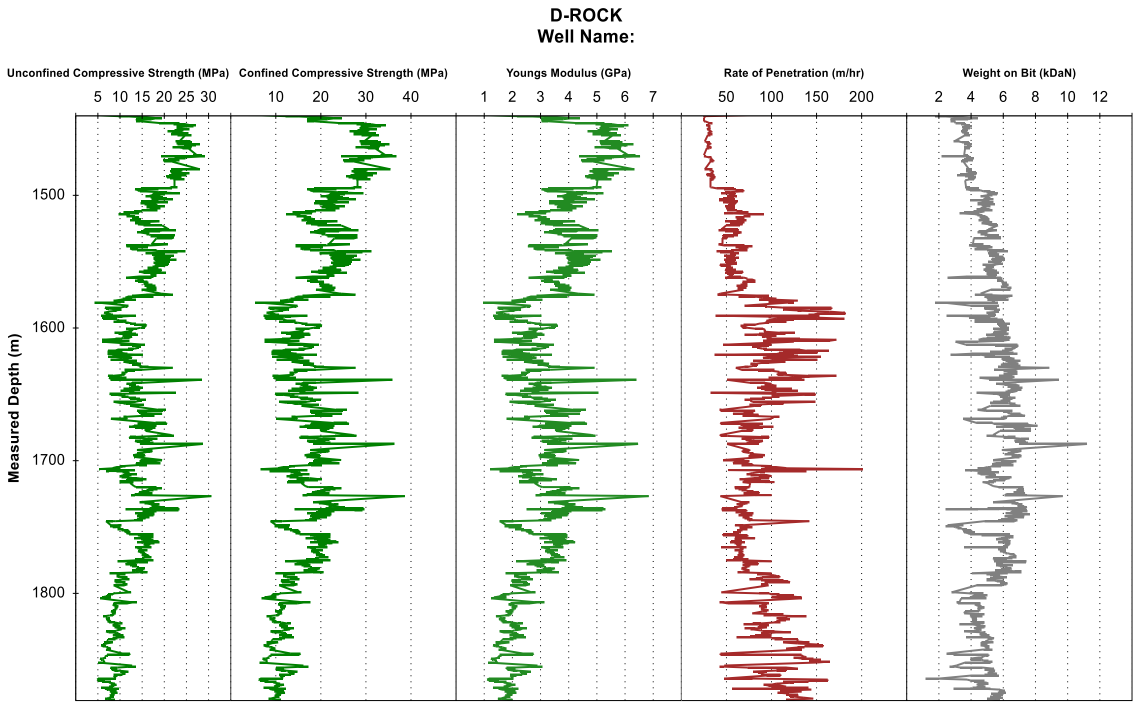
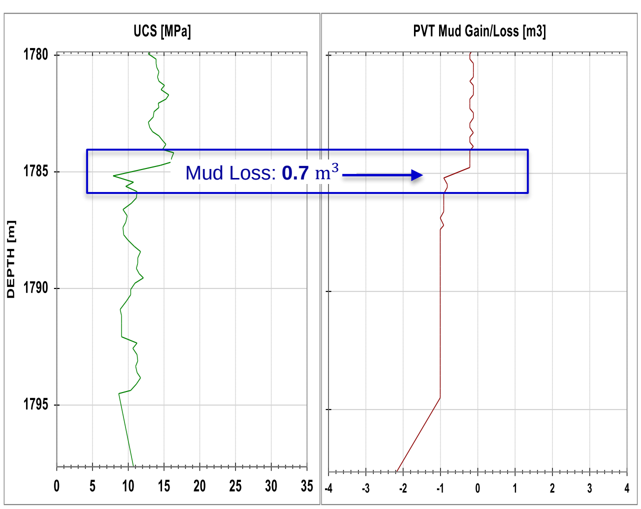


Fig. 2 The strength log example from D-Rock software



DEPTH [m]	RPM [rpm]	UCS_QCrpm [Mpa]
1783.7	40	14.906
1783.86	38	15.31
1784.07	41	14.826
1784.22	38	16.414
1784.42	40	16.077
1784.6	41	16.042
1784.76	41	14.532
1785.2	42	7.902
1785.47	38	10.764
1785.64	46	9.732
1785.88	41	11.3
1786.12	41	11.197
1786.36	43	10.508
1786.64	41	9.271
1786.92	43	9.872
1787.2	40	9.714
1787.42	44	9.305
1787.7	42	9.408
1787.95	41	9.96
1788.23	43	10.891
1788.45	40	11.81
1788.69	40	11.409
1788.94	42	11.392
1789.16	42	11.15
1789.37	41	11.547
1789.59	42	12.19

Fig. 3 Identification of possible natural fracture with weaker rock strength and mud losses

As an example, the software identifies natural fracture at around 1785m with weaker rock strength (UCS) as shown in Fig. 3. In this figure, the UCS suddenly drops to around half at 1785.2m measured depth as shown in the green box at the right side of the spreadsheet. The identification is verified by monitoring mud losses in this zone. The second plot in Fig. 3 shows mud losses of around 0.7 m^3 (blue box) at the same depth along the horizontal wellbore.

Conclusions

Using the D-Series software is simple and cost effective solution to generate rock mechanical properties and to map fractures in reservoirs from typical drilling data. The software estimates effective downhole weight on bit from the wellbore friction analysis and uses it in the inverted ROP model to generate a rock properties log from the surface measurement of drilling data, drill bit information, formation lithology and other easily collected field data.

Possible locations of natural fractures are identified from the rock strengths of horizontal wells in North America using depth-based and 10 sec. time-based drilling data. The results are verified with the corresponding mud losses when drilling the naturally fractured reservoir. Further verifications will be performed with more wells and higher frequency (1 sec.) field data.

The accurate and convenient rock strength log from D-Series software and fracture location identification can be used to evaluate well completion strategies efficiently and in a more cost-effective way with higher net present (NPV) values as a result.

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