Use of Drilling Data to Generate Rock Mechanical and Natural Fracture Property Logs in Horizontal Wells*

Mazeda Tahmeen[1] and Geir Hareland[2]

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[1]Rocsol Technologies Inc., Calgary, Canada (mtahmeen@rocsoltech.com)
[2]Oklahoma State University, Stillwater, Oklahoma, USA (geir.hareland@okstate.edu)

Abstract

Researchers and engineers have been investigating convenient and cost effective techniques to obtain continuous rock mechanical and natural fracture properties along the wellbore in horizontal wells. The conventional techniques are in many cases expensive, uncertain and sometimes difficult and time consuming to process. A convenient system composed of two D-Series software's D-WOB and D-Rock, was developed to generate rock property logs versus depth from available surface drilling data. The D-WOB software calculates effective downhole weight on bit (DWOB) from surface drilling data, drill string information and wellbore survey measurements. The D-Rock software calculates the rock mechanical properties such as confined compressive strength (CCS), unconfined compressive strength (UCS), and Young's modulus (E) using the outputs from D-WOB software, drill bit information and formation lithology. The D-WOB software uses wellbore friction models to estimate the coefficient of friction and effective DWOB from the surface measurement of weight on bit (WOB), hook load, wellbore survey, drilling fluid and drill string information. The software calculates 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-Rock software uses rate of penetration (ROP) models developed to estimate rock properties from drilling parameters, such as flow rate DWOB, RPM, reported bit wear, and drill bit design parameters. The D-Series software was verified using field data from horizontal wells in North America. The depth-based and 10 second time-based drilling data along with collected drilling parameters were used to obtain the rock mechanical logs. The UCS rock strength logs were compared to rock strength logs generated from sonic logs with a very good match. The possible natural fractures and fracture zones were identified from a recognized behavior of the rock strengths (UCS) when penetrating the fractures at different depths. The natural fractures were further identified with the corresponding mud losses when drilling the naturally fractured reservoir. The accurate and convenient rock mechanical log from D-Series software and fracture location identification can be used to evaluate well completion strategies efficiently and in a cost-effective way.

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Geir Hareland
Professor and Continental Resources Chair
Oklahoma State University

Mazeda Tahmeen
Manager, Real-Time Solutions
Rocsol Technologies Inc.

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Presentation Outline

- Challenges of Horizontal Well Logging
- A New Technology to Generate Rock Property Logs
- Drilling Data Models
- Input Data for D-Series Software
- Analysis/Verification with Drilling Data from Horizontal Wells
- Conclusions

Challenges of Horizontal Well Logging

- Continuous monitoring of rock mechanical and natural fracture properties along the wellbore in horizontal wells.

- In horizontal wells, the conventional logging tools usually need to be pushed efficiently along the longer logged section of the wellbore and sometimes difficult to process.

- Possible risks and concerns of trapping logging tools downhole by collapsing wellbore walls.

- Sometimes too late to take operational decisions and make changes in the drilling based on the information obtained using the conventional techniques such as, core analysis and well logging using sonic and resistivity image logs.

- The conventional logging techniques are not done on all wells of the reservoir and in many cases expensive, uncertain and time consuming to process, particularly in horizontal wells.

A New Technology

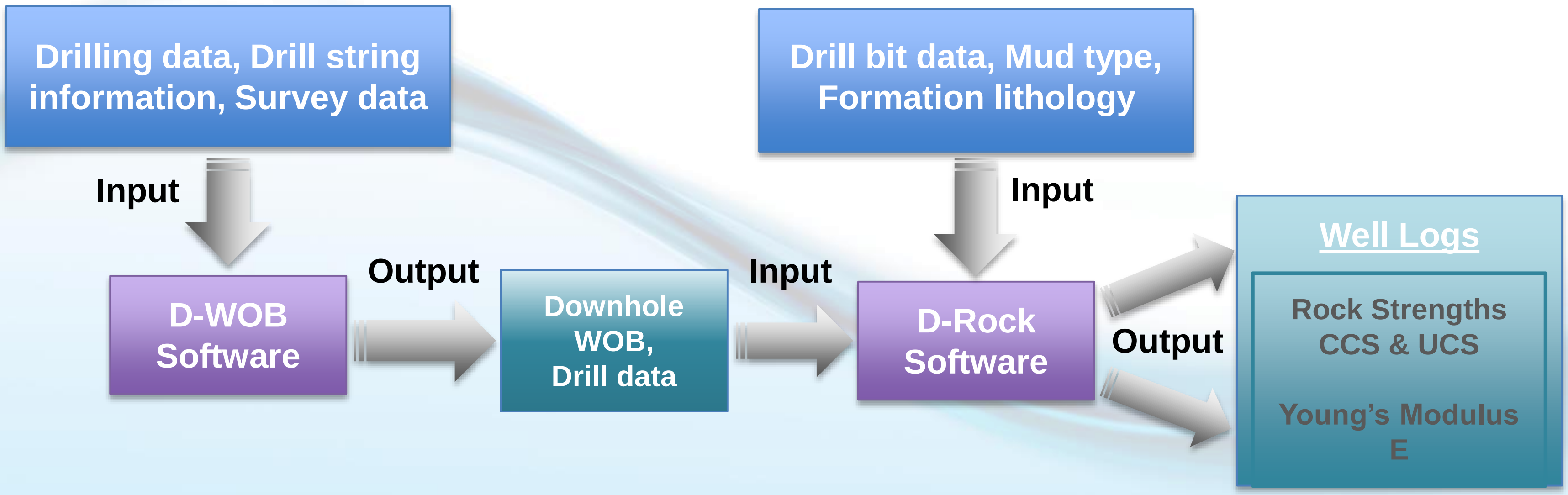
Introduction and Benefits

- A convenient logging technology composed of two D-Series software products: D-WOB and D-Rock.
- The software generates continuous rock mechanical and natural fracture property logs versus depth from available drilling data.
- The properties include confined compressive strength (CCS), unconfined compressive strength (UCS) and dynamic Young's modulus (E).
- The possible natural fractures and fracture zones can be identified from recognized behavior of the rock strengths (UCS) when penetrating the reservoir fractures at different depths and prevent lost circulation.
- Young's modulus, E-log is a measure of rock stiffness and usually used in the fracture width (aperture) calculation in conventional fracture design software.
- The rock mechanical logs and information on natural fractures in reservoir can be used to design an optimal stimulation treatment for maximum well productivity.

A New Technology – Cont'd

D-Series Software

- **D-WOB :** Calculates friction coefficient and downhole weight on bit (DWOB) from drilling data, drill string information and wellbore survey measurement
- **D-Rock :** Calculates rock strengths and Young's modulus using the output of D-WOB software, drill bit information, mud data and formation lithology

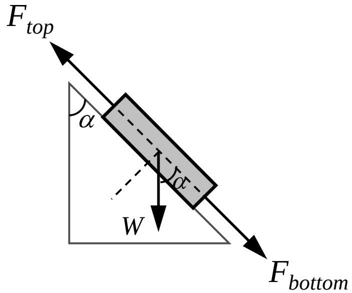


Drilling Data Models

D-WOB uses the force balance model on a drill string element

- **For straight, inclined section** (when the drill bit is on-bottom):

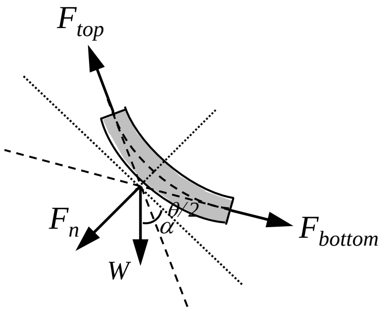
$$F_{top} = \beta w \Delta L\left(\cos\alpha - \mu \sin\alpha\right) + \left(F_{bottom} - DWOB\right)$$



- **For curved section** (when the drill bit is on-bottom):

Tension in Curved Section

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



Compression in Curved Section

$$F_{top} = \left(\beta w \Delta L\right)\left[\cos\left(\frac{\alpha_{top} + \alpha_{bottom}}{2}\right)\right] - \mu F_n + \left[F_{bottom} - DWOB\right]$$

$$F_n = \left(\left[\left(F_b - DWOB\right)\left(\varphi_{top} - \varphi_{bottom}\right)\left\{\sin\left(\frac{\alpha_{top} + \alpha_{bottom}}{2}\right)\right\}\right]^2 + \left[\left\{\left(F_b - DWOB\right)\left(\alpha_{top} - \alpha_{bottom}\right)\right\} + \left\{\left(\beta w \Delta L\right)\sin\left(\frac{\alpha_{top} + \alpha_{bottom}}{2}\right)\right\}\right]^2\right)^{1/2}$$

$$W = \beta w \Delta L$$

$DWOB$: down hole weight on the bit F : force / hook load w : unit weight of drill string ΔL : length of element
β : buoyancy factor W : buoyed weight μ: friction coefficient α : inclination angle φ : azimuth angle θ : dogleg angle

Drilling Data Models – Cont'd

D-Rock uses the inverted ROP drill bit model to define rock strengths

- **Confined Compressive Strength (CCS):**

$$CCS = \left[\frac{ROP_{field}}{K \times DWOB^{b_1} \times RPM^{c_1} \times h_x \times W_f \times B_x} \right]^{\frac{1}{a_1}}$$

For **PDC** bit : $h_x = f\left(HSI, ROP, D_b, JSA\right)$

For **Rollercone** bit : $h_x = f\left(HSI, ROP, D_b\right)$

- **Unconfined Compressive Strength (UCS):** $UCS = CCS / \left(1 + a_s \times P_c^{b_s}\right)$

- **Young's Modulus (E):** $E = UCS \times a_E$

DWOB : down hole weight on bit from D-WOB ***ROP*** : rate of penetration ***Wf*** : bit wear function ***RPM*** : rotation per minute
K : empirical constant ***Db*** : bit diameter ***Bx*** : *f* (drill bit properties) ***HSI*** : horsepower per sq. inch ***JSA*** : junk slot area
Pc : confining pressure a_1, b_1, c_1 : drill bit constants a_S, b_S, a_E : empirical constants obtained from triaxial test data

Input Data for D-Series

❑ D-WOB

▪ Time-based Data:

- Date-Time
- Measured/Hole Depth
- Bit Depth
- Surface Hook Load
- Surface Weight on Bit (WOB)
- Rate of Penetration (ROP)
- Standpipe Pressure (SPP)
- Rotary RPM
- Flow rate/Total Pump Output (TPO)

▪ Survey Data:

- Measured Depth
- True Vertical Depth (TVD)
- Azimuth
- Inclination

▪ Depth-based Data:

- Measured/Hole Depth
- Surface Hook Load
- Surface Weight on Bit (WOB)
- Rate of Penetration (ROP)
- Standpipe Pressure (SPP)
- Rotary RPM
- Flow rate/Total Pump Output (TPO)
- MWD Gamma
- Mud Density/Mud Weight
- Differential Pressure
- Pore Pressure
- Plastic Viscosity

▪ Drill string Data:

- Length, Inner diameter and Outer diameter of BHA and drill string
- Nominal/Unit Weight of drill string
- Depth In and Depth Out of drill string

▪ Additional Data:

- Static Hook Weight, Overall/Single Sheave Efficiency, Number of Lines

Input Data for D-Series – Cont'd

D-Rock

Depth-based Data:

- Measured/Hole Depth
- Surface Hook Load
- Surface Weight on Bit (WOB)
- Rate of Penetration (ROP)
- Standpipe Pressure (SPP)
- Rotary RPM
- Flow rate/Total Pump Output (TPO)
- MWD Gamma
- Mud Density/Mud Weight
- Pore Pressure
- Plastic Viscosity

Drill Bit Data:

- Type and Diameter of Drill Bits
- IADC Code (mandatory for Tricone bit)
- Depth In and Depth Out of drill string
- Wear In and Wear Out
- Number and Diameter of Jets/Nozzles
- Number and Diameter of Cutters
- Cutter Thickness
- Number of Blades
- Back and Side Rack Angles
- Junk Slot Area

Formation and Mud Data:

- Rock Formation Type/Lithology
- Mud Type (Oil/Water based)
- Mud Motor Constant

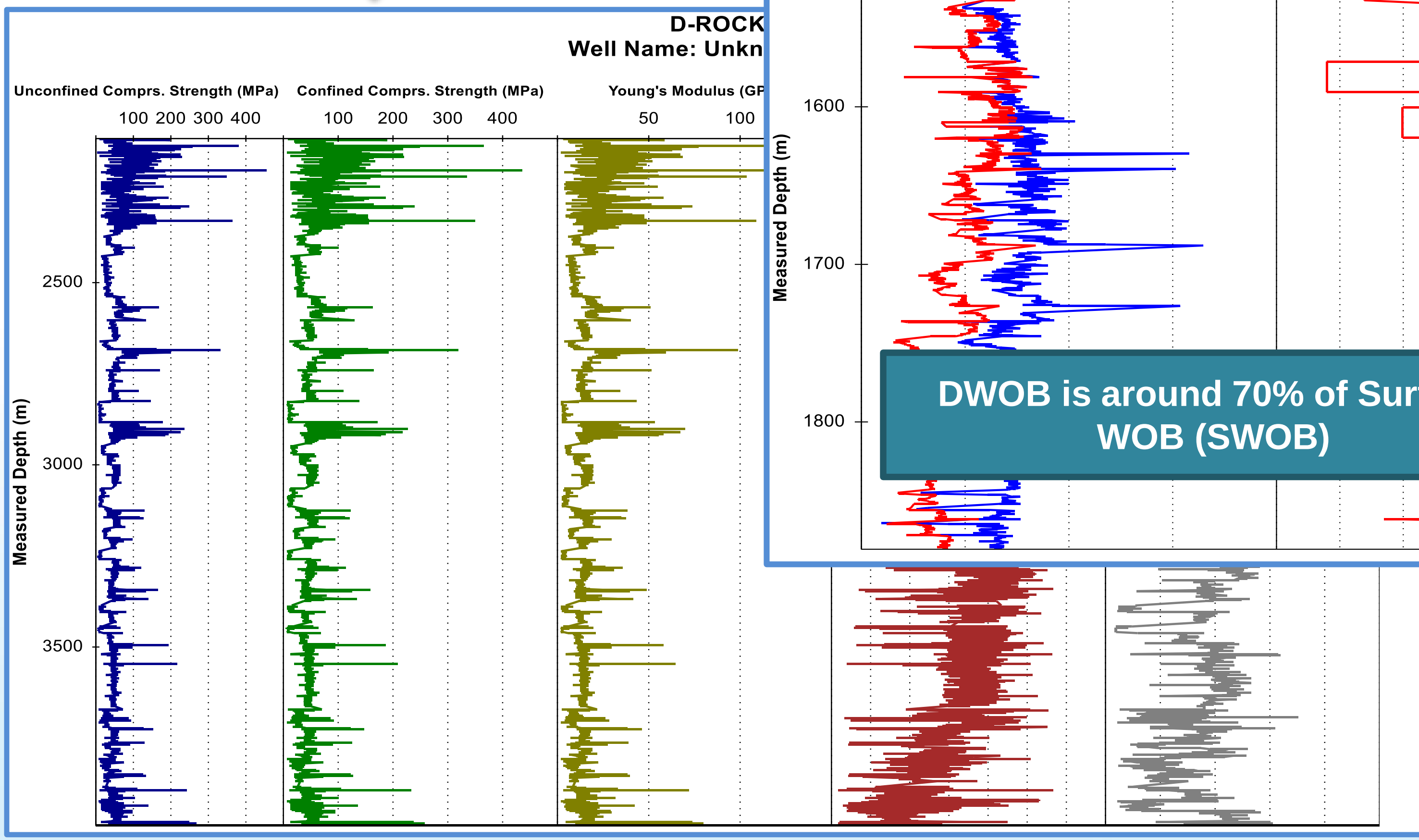
Laboratory Triaxial Data:

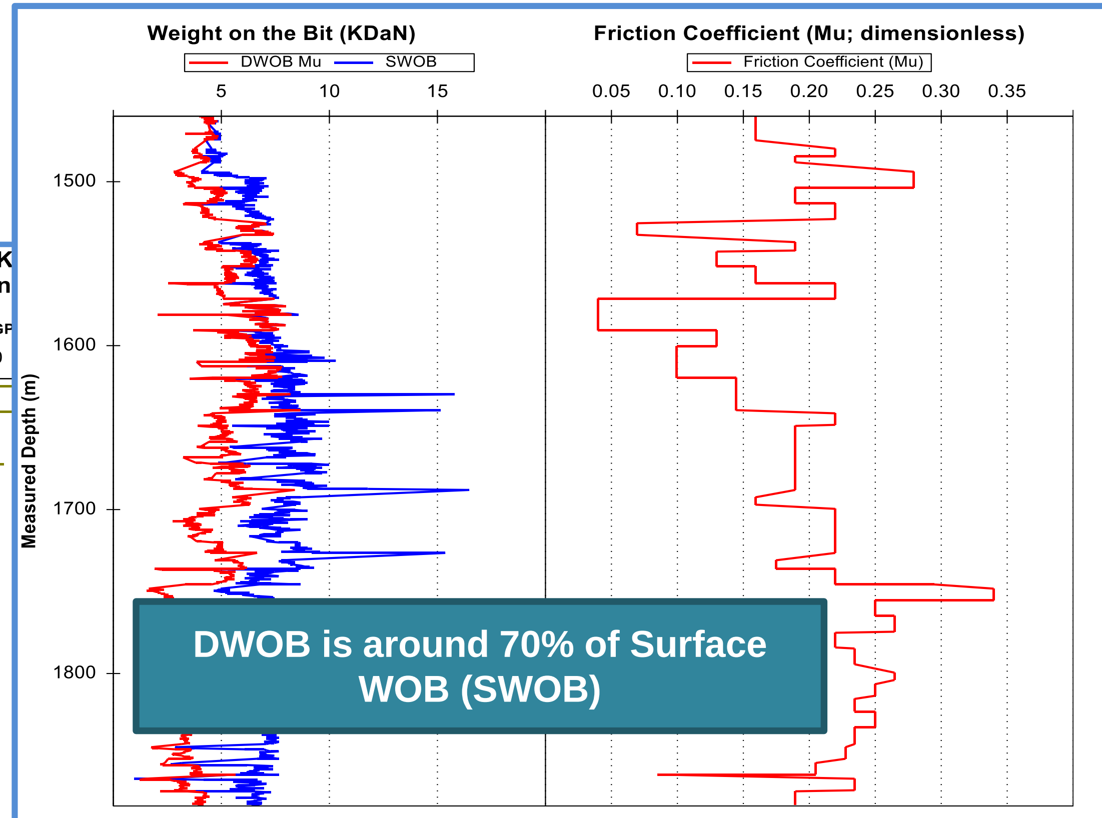
- Effective Confining Pressure
- Confined Compressive Strength (CCS)
- Average Unconfined Compressive Strength (UCS)

Data Analysis

❑ Downhole WOB (DWOB) from D-WOB and Strength Log from D-Rock

From D-Rock

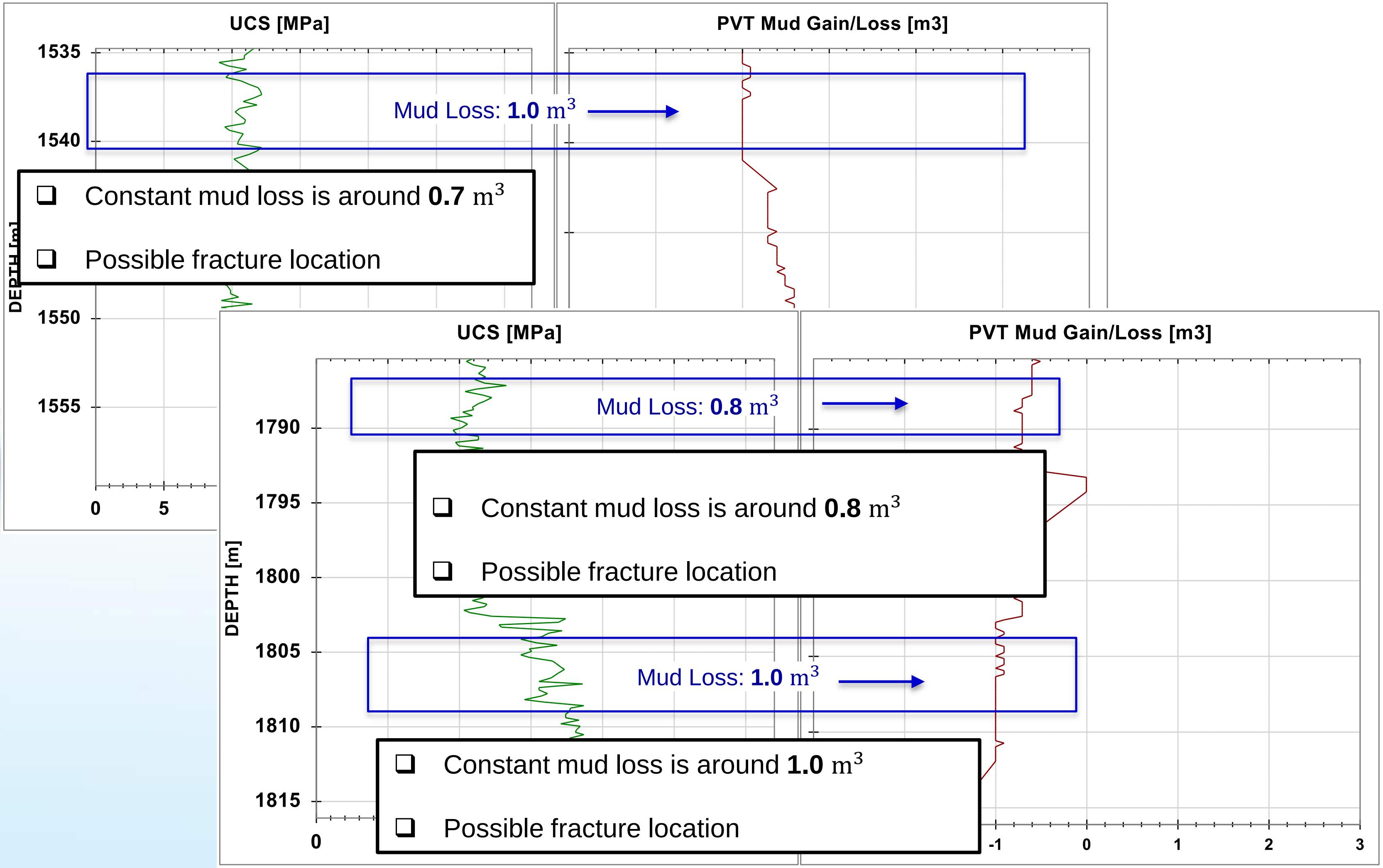




From D-WOB

Data Analysis – Cont'd

- Mud losses are common in naturally fractured formation



D-Series Verification

A case study by a large E&P company

Well Information

- Lower Triassic Montney formation
- Montney: Dark grey siltstone with minor sandstone to dolomite siltstone
- Pore pressure: 14.58 kPa/m; Specific gravity: 1.49: 3 – 10% porosity
- Horizontal section: 2600m – 4490m
- Underbalanced drilling with oil and water based mud
- ReedHycalog drill bit: 200 mm

Results from Case Study

- UCS prediction is consistent with that estimated from sonic logs
- Average UCS: 99.57 MPa: Average Young's Modulus (YM): 29.64 GPa
- Davey (2012) reported UCS of 117 – 136 MPa for the Montney formation
- Similar analysis on an identical well yields average UCS around 109 MPa and YM around 32 GPa
- Results are also consistent with laboratory measurements

Conclusions

- The D-Series technology is simple and time efficient solution to generate rock mechanical properties from typical drilling data and help for enhanced fracture design.
- The depth-based and 10 second time-based drilling data along with other collected drilling parameters from horizontal wells in North America were used to obtain the rock mechanical logs.
- The UCS rock strength logs were compared to the rock strengths generated from sonic logs with a very good match.
- Possible locations of natural fractures were identified from the rock strengths (UCS) and verified with the corresponding mud losses when drilling the naturally fractured reservoir.
- High frequency analysis (1-2 cm) of the data can provide much higher resolution than the limitations of most logging tools (30 cm).
- The high resolution and convenient rock mechanical and natural fracture property logs can ensure better decision making to evaluate well completion strategies efficiently and in cost-effective way.

Thank you

Contact:

Mazeda Tahmeen, Ph.D., P.Eng.
Manager, Real-time Solutions

Rocsol Technologies Inc.
3553, 31 Street NW
Calgary, Alberta, Canada T2L 2K7

E-mail: mtahmeen@rocsoltech.com