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Complete Geomechanical Property Log from Drilling Data in Unconventional Horizontal Wells

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Presentation Outline

- Challenges of Horizontal Well Logging
- A New Technology to Generate Rock Property Logs
- Drilling Parameter Models – D-WOB and D-Rock
- Data Analysis - DWOB Calculations
- Formation Characteristics from Core
- Geomechanical Properties from D-Rock
- Result Verification, Conclusions and References

Challenges of Horizontal Well Logging

- Conventional logging and rock mechanical testing are expensive (logging cost and rig time) and has uncertainties.
- Continuous monitoring of rock mechanical and reservoir properties along the wellbore in horizontal wells.
- In horizontal wells, the conventional logging tools can sometimes difficult to process (depth correlations and averaged data).
- Possible risks and concerns of trapping logging tools downhole.
- Sometimes too late to make 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 therefore not done on all unconventional wells and mainly due to associated cost, uncertain and time consuming to process.

A New Technology

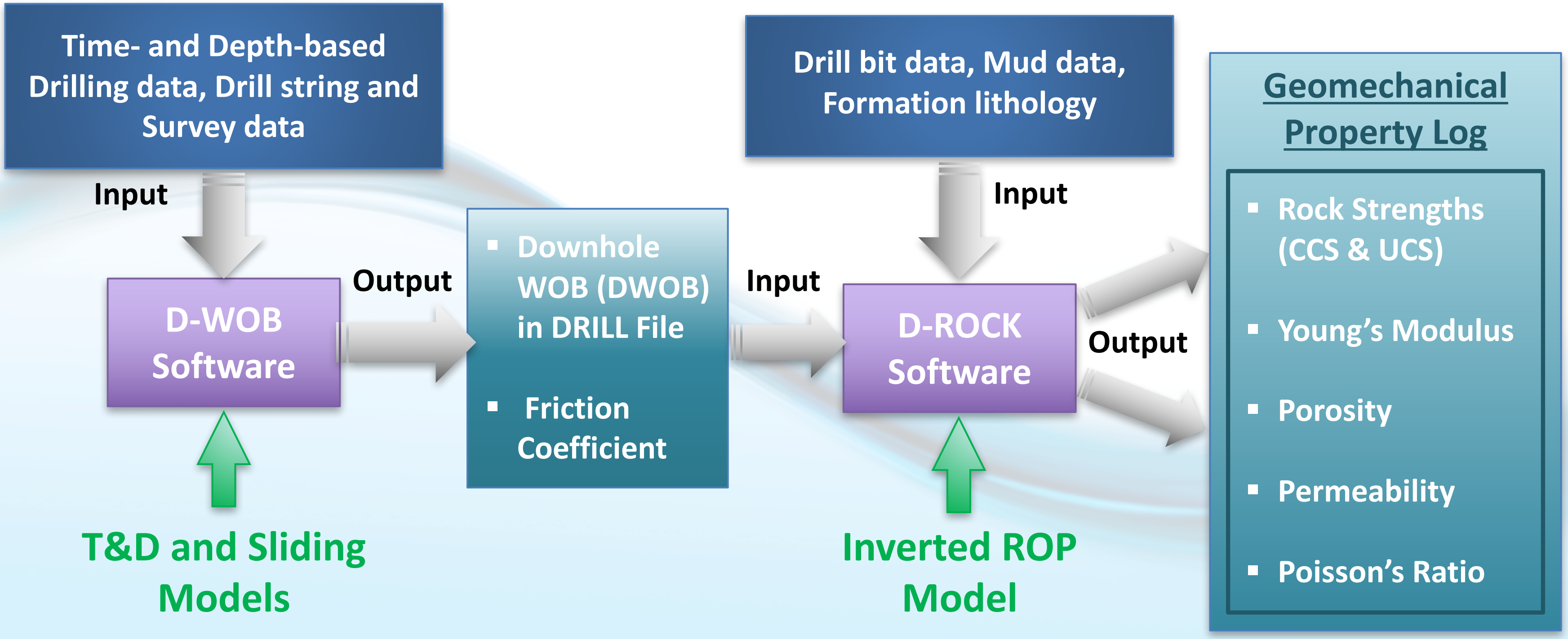
Introduction and Benefits

- D-Series is a convenient logging technology composed of two software products: D-WOB and D-Rock
- D-WOB uses surface drilling data to determine drill string friction coefficient in the wellbore through T&D models and therefrom the downhole weight on bit (DWOB)
- D-Rock generates continuous geomechanical property logs versus depth from drilling data collected during the drilling process (and some formation mapped correlations) through an inverted ROP model and does not add cost
- The properties include confined compressive strength (CCS), unconfined compressive strength (UCS), Young's modulus (E), porosity, permeability and Poisson's ratio
- A detailed geomechanical and reservoir property logs can be used to design optimal stimulation (through selective perforation/zoning) treatment for maximum well productivity

Overview of D-Series Technology

- **D-WOB :** Uses torque & drag (T&D) and sliding models to calculate friction coefficient (FC) and downhole weight on bit (DWOB) from drilling data, drill string information and wellbore survey measurement

- **D-ROCK :** Uses inverted ROP model to calculate rock strengths (CCS and UCS), Young's modulus, porosity, permeability and Poisson's ratio using the output from D-WOB, drill bit information, mud data and formation lithology

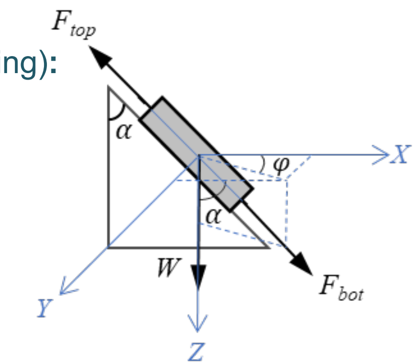


Drilling Parameter Models – D-WOB

❑ D-WOB uses the force balance (T&D) model on a drill string element

- **For straight, inclined section – (a)** (when the drill bit is off-bottom and lowering):

$$F_{top} = \beta w \Delta L(\cos\alpha - \mu \sin\alpha) + F_{bot}$$ (Aadnoy, 2010)

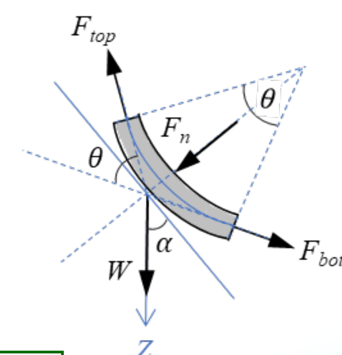


(a)

- **For curved section – (b)** (when the drill bit is on-bottom and lowering) **:**

Tension in Curved Section (Aadnoy, 2010 and Fazaelizadeh et.al., 2010)

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



(b)

Compression in Curved Section (Johancsik et.al., 2010)

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

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

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

$DWOB$: 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 Parameter Models – D-Rock

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

- **Confined Compressive Strength (CCS):** (Hareland et. al., 2010 and Kerkar et.al., 2014)

$$CCS = \left[\frac{ROP}{K.DWOB^{b_1}.RPM^{c_1}.h_x.W_f.B_x}\right]^{1/2}$$

$W_f = f$ (Drill bit wear)

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

For **PDC** bit : $B_x = f(RPM, D_b, B_n, SRA, BRA)$

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

❑ Other geomechanical correlations in D-Rock

- **Young's Modulus (E):** $E = CCS\,.a_E.(1 + P_c)^{b_E}$
- **Porosity (∅):** $\emptyset = k_1.UCS^{(-k_2)}$ (Cedola et. al., 2017a)
- **Permeability (∅):** $K_p = k_3.\emptyset^{k_4}$
- **Poisson's Ratio (PR):** Calculated from UCS and Mohr Failure Envelope

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 ***a1, b1, c1*** : drill bit constants ***as, bs, aE, bE*** : constants obtained from triaxial test data for rock type
k1, k2, k3, k4 : reservoir specific constants

Input Data for D-Series

❑ D-WOB

- ***Drilling data:*** date & time, measured/hole depth, bit depth, weight on bit (WOB), hook load, rate of penetration (ROP), rotary RPM, stand pipe pressure (SPP), flow rate, differential pressure and pore pressure
- ***Survey data:*** measured depth, true vertical depth (TVD), inclination and azimuth
- ***Drill string details:*** lengths, inner diameter, outer diameter and unit weights of drill string sections such as, bit and BHA components, drill pipes (DPs) and HWDPs
- ***Additional data:*** weight of travelling block, number of lines, single sheave efficiency and mud weight

❑ D-Rock

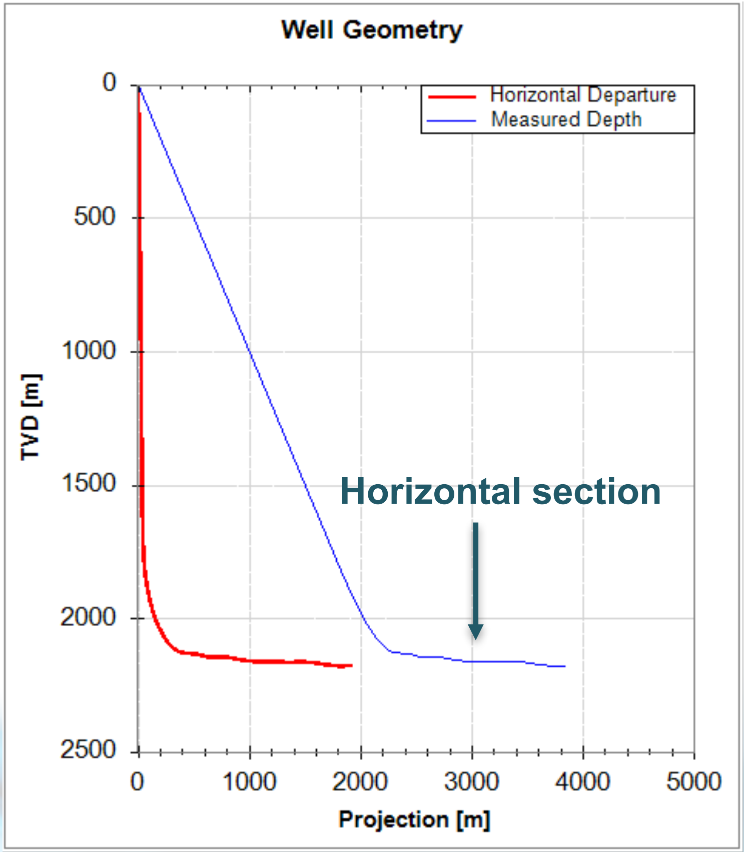
- ***Drill data:*** output data file from D-WOB including measured/hole depth, TVD, downhole weight on bit, ROP, RPM, SPP, flow rate, pore pressure and mud weight
- ***Drill bit details:*** type of drill bit (PDC or Rollercone), bit diameter, IADC code, bit wear in and wear out, number and diameter of bit nozzles
- ***Mud and formation data:*** drilling mud type (water or oil), mud motor constants and formation name
- ***Laboratory triaxial data:*** confining pressure, CCS, average UCS and Young's modulus

Data Analysis

Utilizes drilling data from horizontal wells in North America

❑ Wellbore Profile of Well A

- Based on measured depth, Azimuth, Inclination and true vertical depth (TVD) of survey data
- The total drilled depth is around 3600m with dogleg up to 10 deg/30m
- The heel is at around 2580m



❑ Additional Information for Data Analysis

- The horizontal section from drilled depth 2640m+ is considered for this analysis
- A sliding model was considered to calculate DWOB while sliding and the model is (Wu and Hareland, 2015),

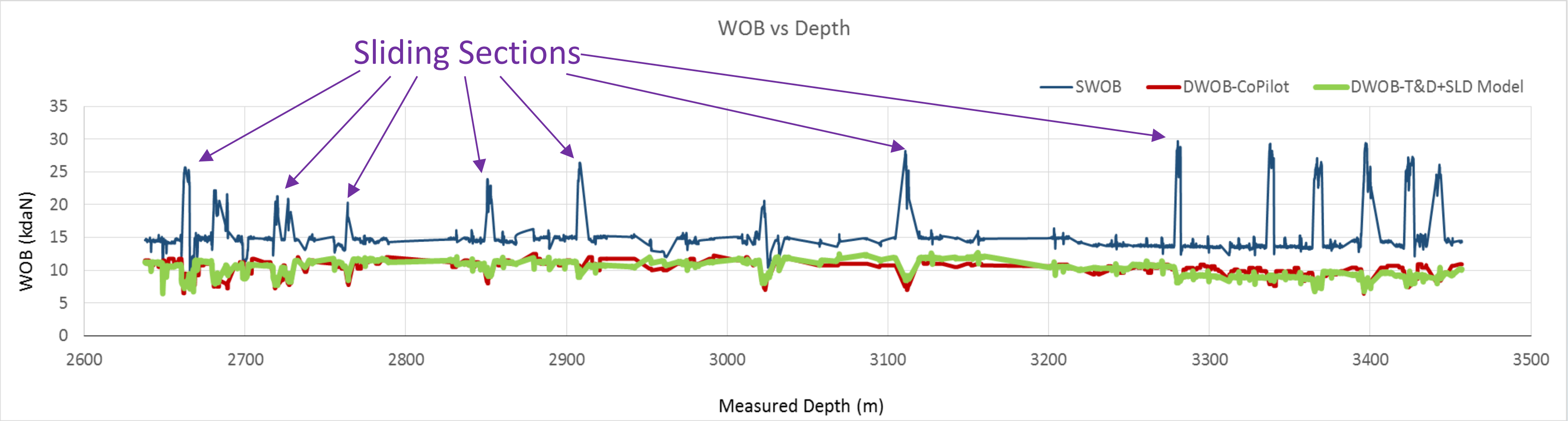
$$DWOB_{sliding} = K_S . DP$$

Ks : Sliding constant, *Ks* = *f* (*DP*, *DWOB* from rotary drilling)

DWOB Calculations

- ❑ **If the calculation <u>does not consider</u> Sliding Model** (only T&D model)

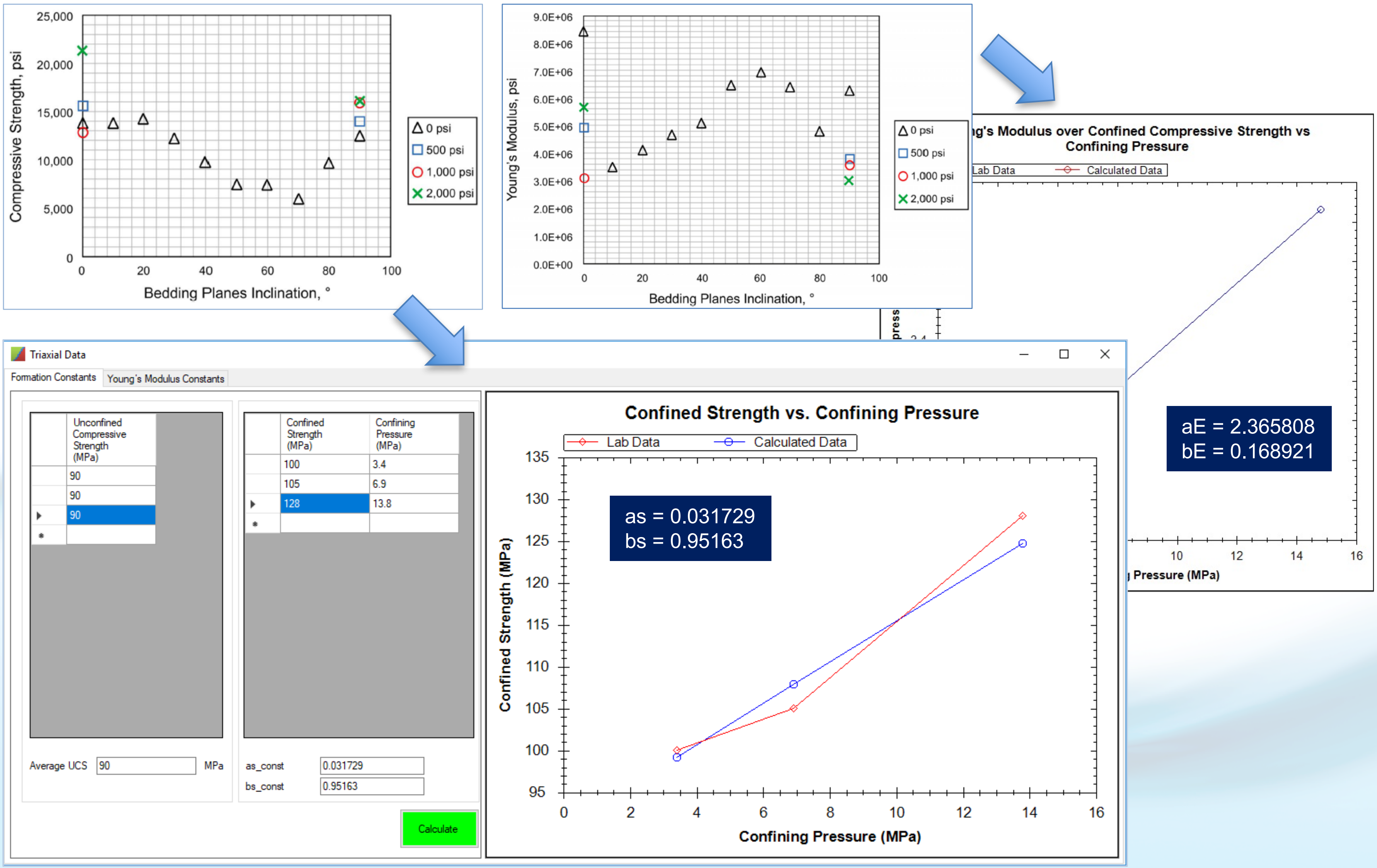
- ❑ **If the calculation <u>considers</u> Sliding Model** (both T&D and Sliding models)



- ❑ Estimated friction coefficient from **0.09 to 0.18** and effective DWOB was observed around **77.6%** of the surface measured WOB

Formation Characteristics from Core

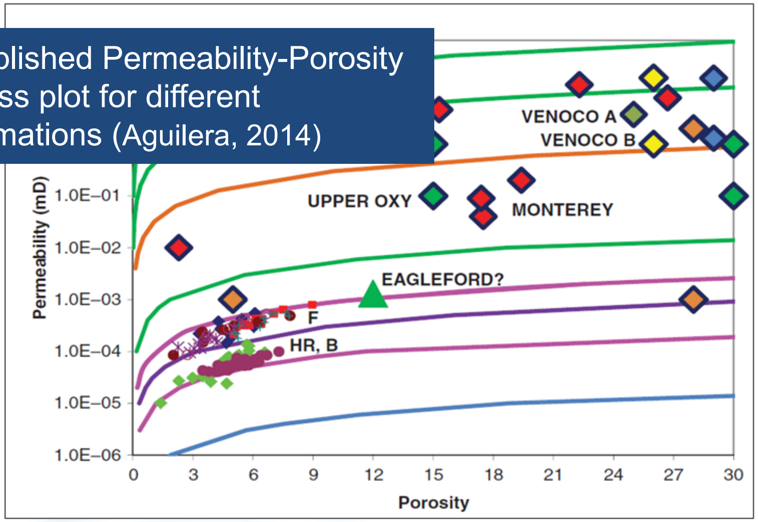
- **Formation constants based on published laboratory test data for Eagle Ford** (Hu, et. al., 2014)



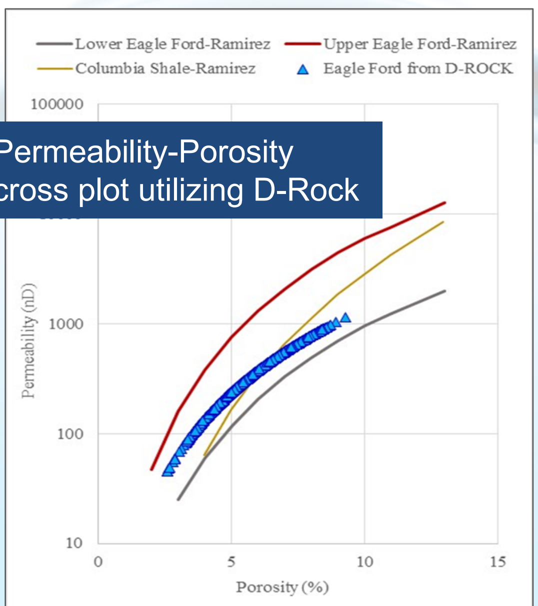
Geomechanical Properties from D-Rock

- UCS from D-Rock is used in Porosity and Poisson's ratio correlations and Porosity in Permeability correlation

Published Permeability-Porosity cross plot for different formations (Aguilera, 2014)



Permeability-Porosity cross plot utilizing D-Rock

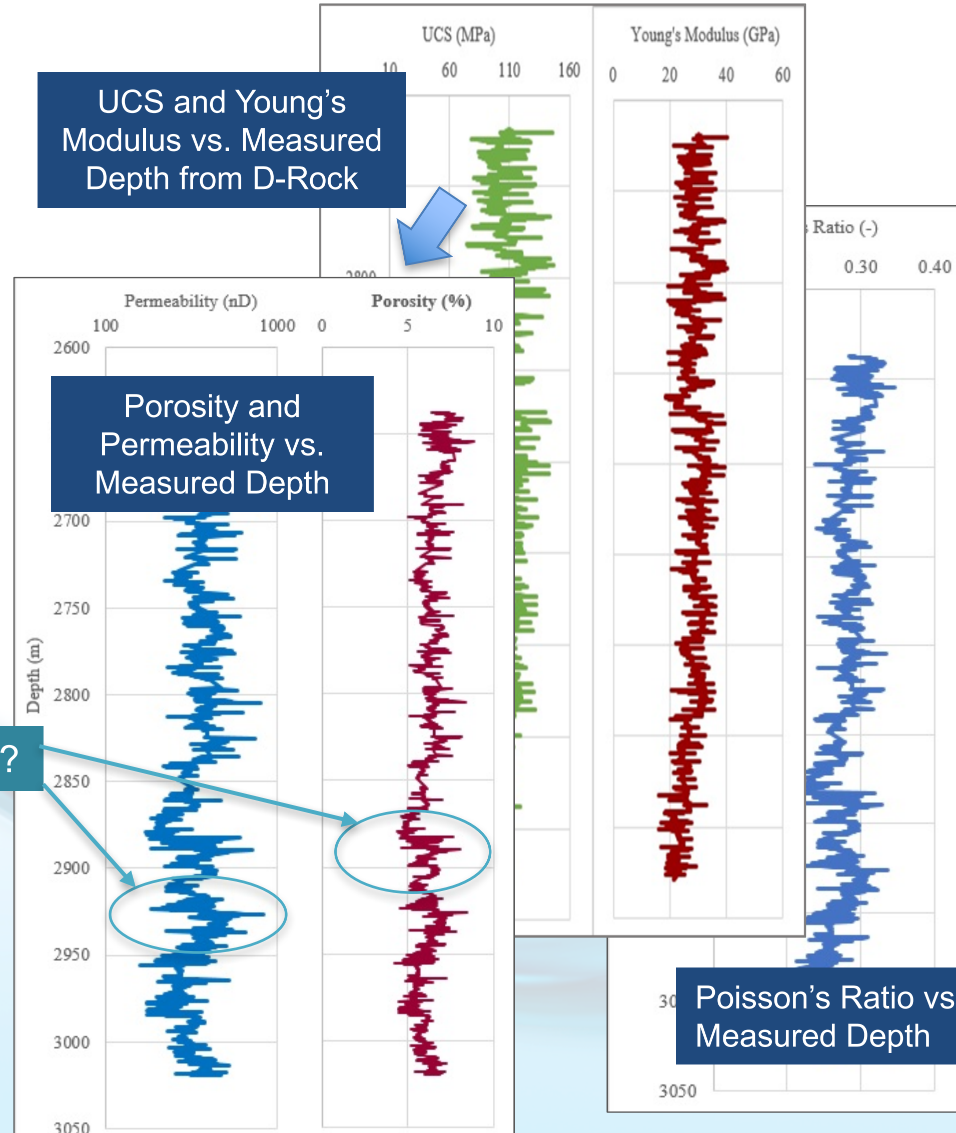


UCS and Young's Modulus vs. Measured Depth from D-Rock

Porosity and Permeability vs. Measured Depth

Sweet spots?

Poisson's Ratio vs. Measured Depth



Result Verification

❑ Case study for the Lower Eagle Ford formation

- ❑ Prediction on geomechanical properties are consistent with laboratory determined rock properties
- ❑ Average UCS: 102.48 MPa and average Young's Modulus (YM): 28.21 GPa
- ❑ Sone reports Young's modulus values for the lower Eagle Ford in the range from 25 to 34 GPa (Sone, 2012)
- ❑ Average Porosity: 5.65% and average Poisson's Ratio: 0.26
- ❑ Porosity values for the Eagle Ford formation are reported in the range from 2% to 15% (Walls et al., 2011)

Conclusions

- Unlike the conventional logging techniques, Rocsol D-Series technology uses routinely collected drilling data to calculate the geomechanical properties utilizing two D-Series software, D-WOB and D-Rock
- A more detailed geomechanical and reservoir property log for each well can be obtained unlike the current logging practice (1 in 10 or I in 20 wells) in unconventional reservoirs
- Detailed information in the rock property logs can be used as inputs to map sweet spots and optimize the hydraulic fracturing process to maximize NPV (Net Present Value)
- D-Series technology can potentially lead to optimize completion and stimulation design of the shale reservoir, using only drilling data collected during normal drilling operations at no additional cost
- Field testing and further verifications will be performed on more test wells with high frequency drilling data

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Thank you