drilling IADC/SPE DRILLING CONFERENCE AND EXHIBITION

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Pore Pressure Estimation Using Mechanical Specific Energy (MSE) and Drilling Efficiency

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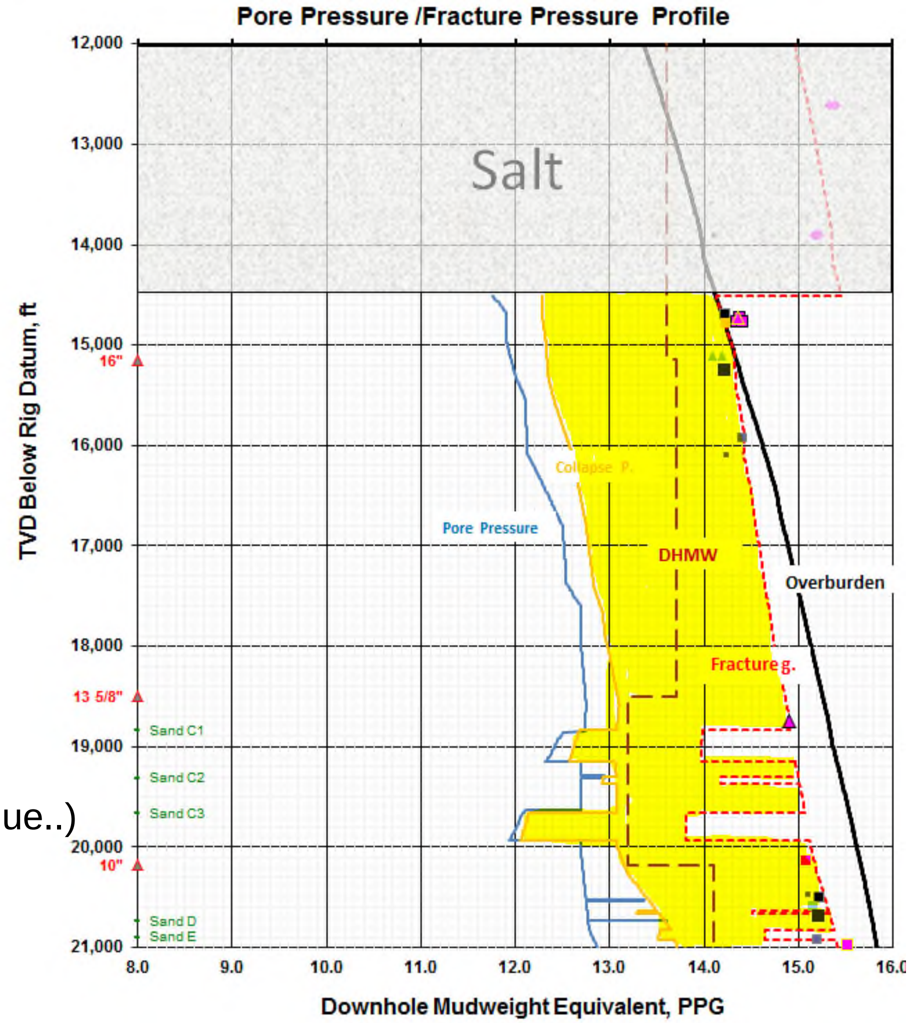
SPE International Society of Petroleum Engineers IADC

Pore Pressure

- Lower bound of Drilling Window
- Collapse Pressure (wellbore stability)
- Fracture Gradient

Pore Pressure Estimation

- Direct Measurements (permeable formations)
  - FPWD, MDT, DST,..
  - Kicks, influx and gas data…
- Indirect estimates (for shales)
  - Logs (Sonic, Resistivity, GR,…)
  - Drilling Mechanics data (ROP, RPM, WOB, Torque..)



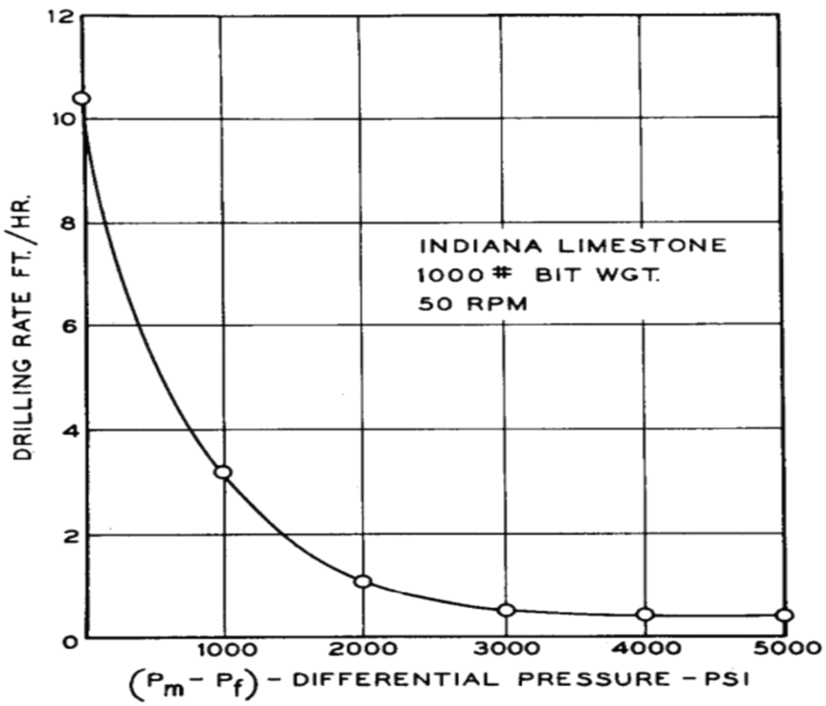
OUTLINE

- Pore pressure and drilling mechanics data
- d-exponent method
- Mechanical Specific Energy (MSE)
- MSE and pore pressure
- Drilling Efficiency and Pore pressure Workflow
- Field Example
- MSE-based Pore Pre. vs dx-base Pore Pressure
- Downhole vs. Surface data
- Torque @ bit measurement & MSE

Pore Pressure & Drilling Performance

EFFECT OF DIFFERENTIAL PRESSURE ON DRILLINC RATE,

INDIANA LIMESTONE.



HUGHES TOOL CO.

SPE,AIME 1094-G, 1959

d-Exponent Method

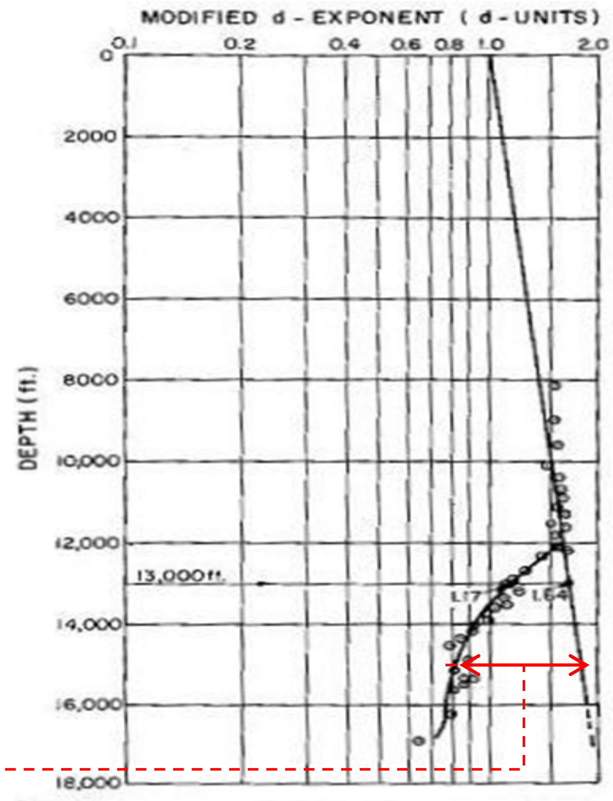
Bingham drilling model, 1965 $ROP = K \times RPM \left(\frac{WOB}{d_{bit}}\right)^{dX}$

Jorden and Shirley in 1966 $dX = \frac{\log\left(\frac{ROP}{60\ RPM}\right)}{\log\left(\frac{12\ WOB}{d_{bit}}\right)}$

Rehm and McClendon,1971 (corrected for Mud Weight used)

$$dXc = \frac{\rho_n}{\rho_w} dX$$

$$p = \frac{dXc_{,n}}{dXc} p_n$$



Mechanical Specific Energy (MSE)

Energy required to destroy a unit volume of rock.

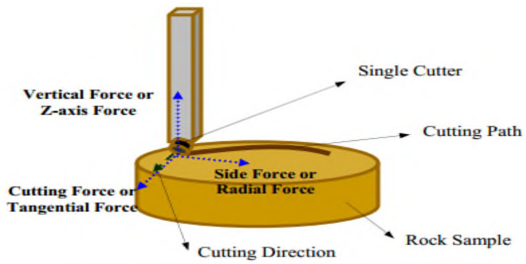
$$MSE = \frac{480 \times T \times RPM}{d_{bit}^{2} \times ROP} + \frac{4 \times WOB}{\pi d_{bit}^{2}}$$

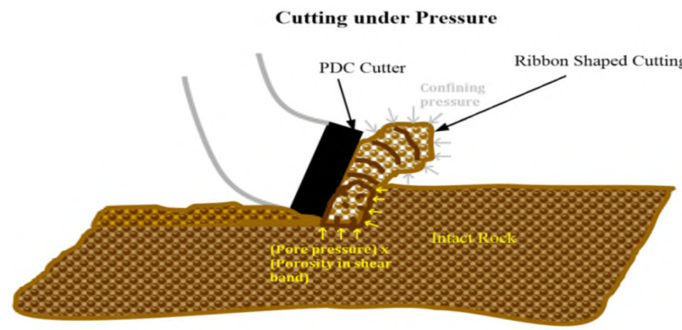
Teale (1965)

T	Torque, ft.lb
WOB	weight on bit, lbf
ROP	rate of penetration, ft/hr
RPM	revolutions per minute, min^{-1}
d_{bit}	Bit diameter, in
MSE	mechanical specific energy, **psi**

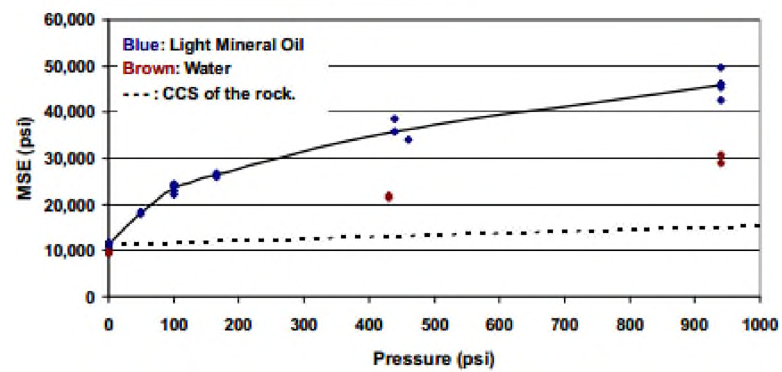
Pore Pressure & MSE: Experimental Work

University of Tulsa
Rafatian 2009 & Akbari 2014





Specific Energy as a Function of Pressure in Indiana Limestone

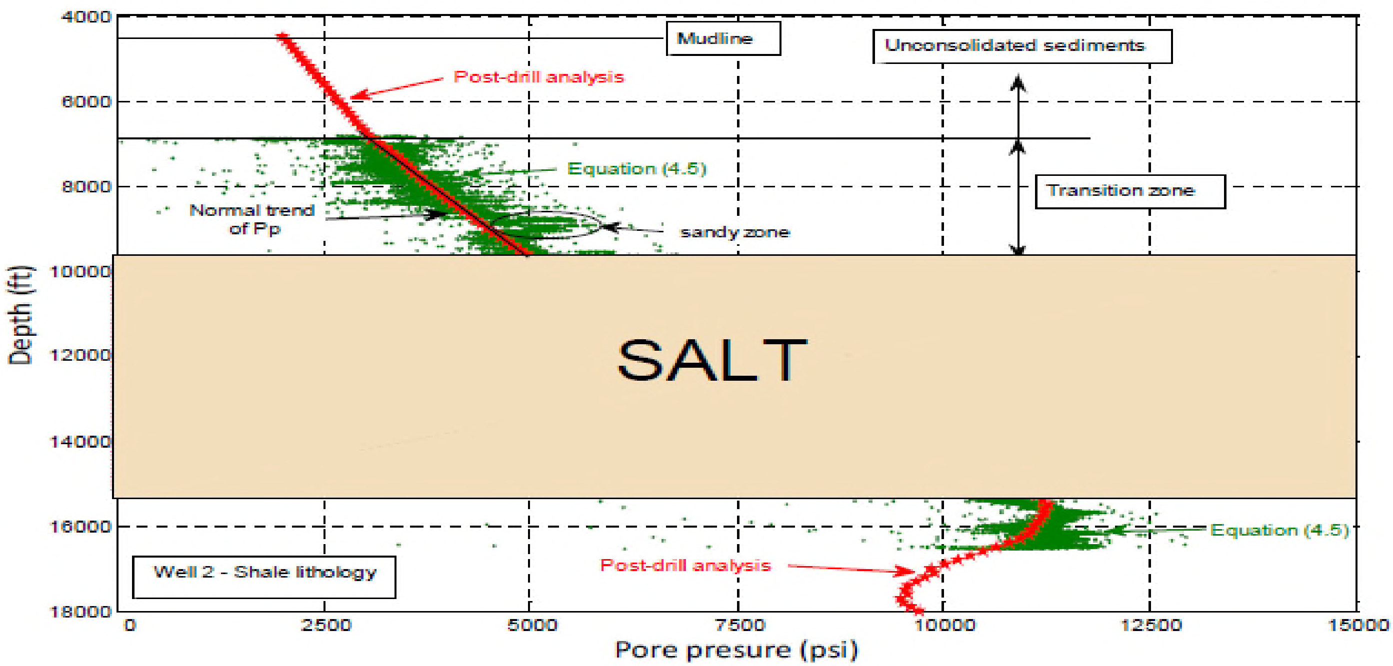


Pore Pressure from MSE (previous work)

J. Cardona et al. (2011)

Texas A&M University (BP sponsored)

$$\frac{P_P}{D} = \frac{OB}{D} - \left[\frac{OB}{D} - \left(\frac{P_P}{D}\right)_N\right]\left(\frac{MSE_o}{MSE_N}\right)^n$$



Borehole Environment

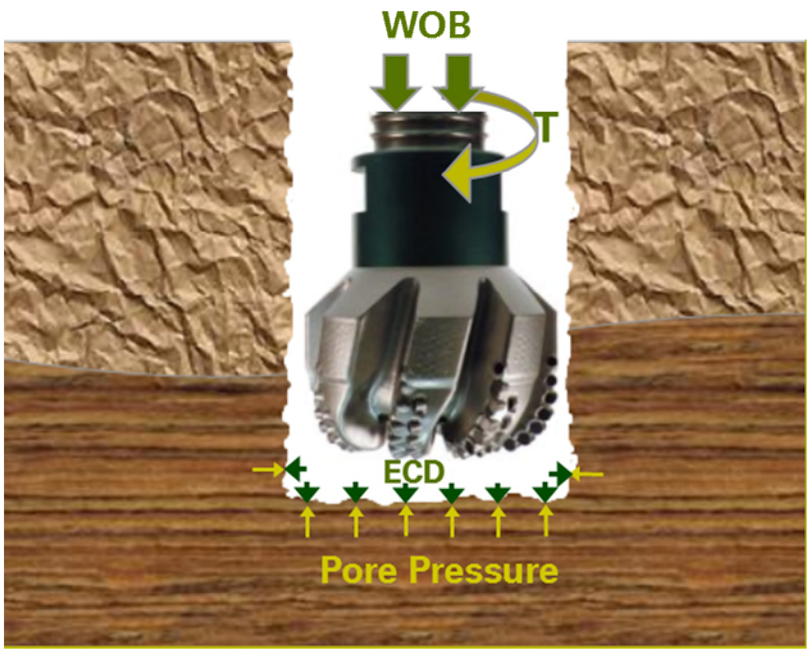
Confined Compressive Strength (CCS)

$$CCS = UCS + \Delta p \left(\frac{1+\sin\theta}{1-\sin\theta} \right)$$

UCS	Unconfined Compressive Strength, psi
θ	angle of Internal friction, Rock property
Δp	Confining Pressure, psi
CCS	Confined Compressive Strength, psi

Drilling Efficiency:

$$DE = \frac{Rock\ Strength\ (insitu)}{Energy\ required\ to\ break} = \frac{CCS}{MSE}$$



$$\Delta p = ECD - PP$$

Drilling Efficiency (DE) and Pore Pressure

$$DE = \frac{Rock\ Strength\ (insitu)}{Energy\ required\ to\ break} = \frac{CCS}{MSE}$$

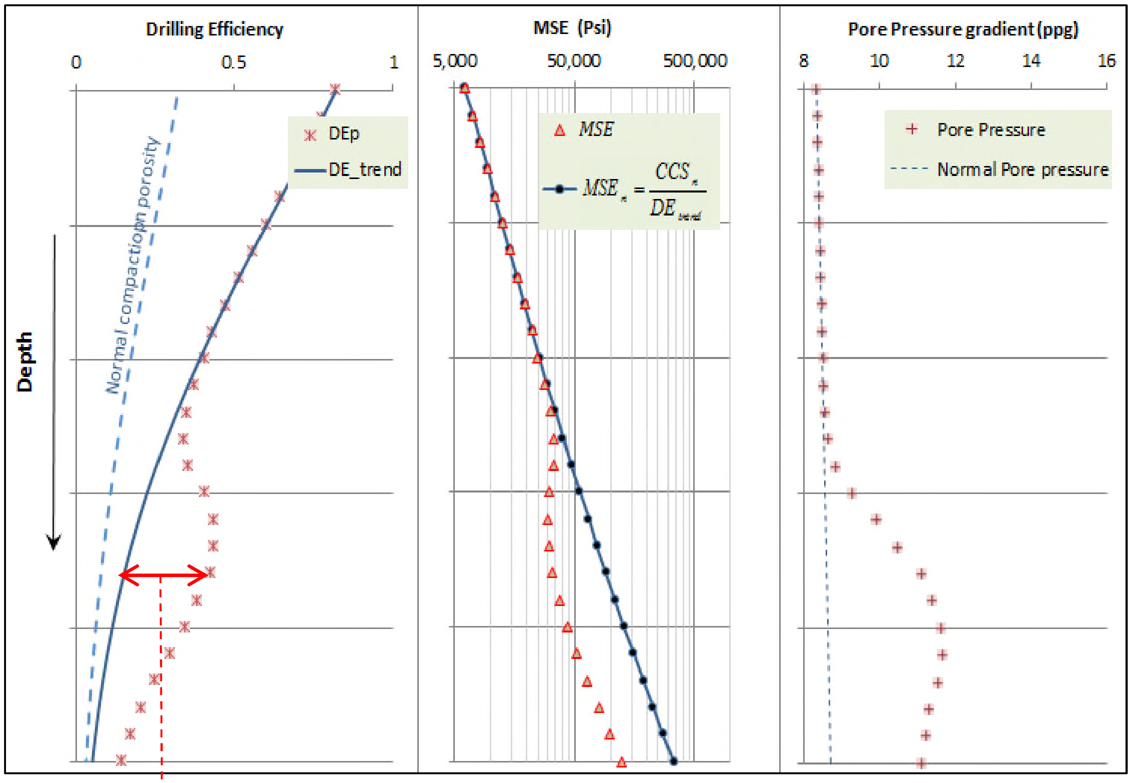
$$DE_p = \frac{CCS_p}{MSE}$$

$$DE_{trend} = a\,\varphi_n^b$$

$$\Delta DE = DE_p - DE_{trend}$$

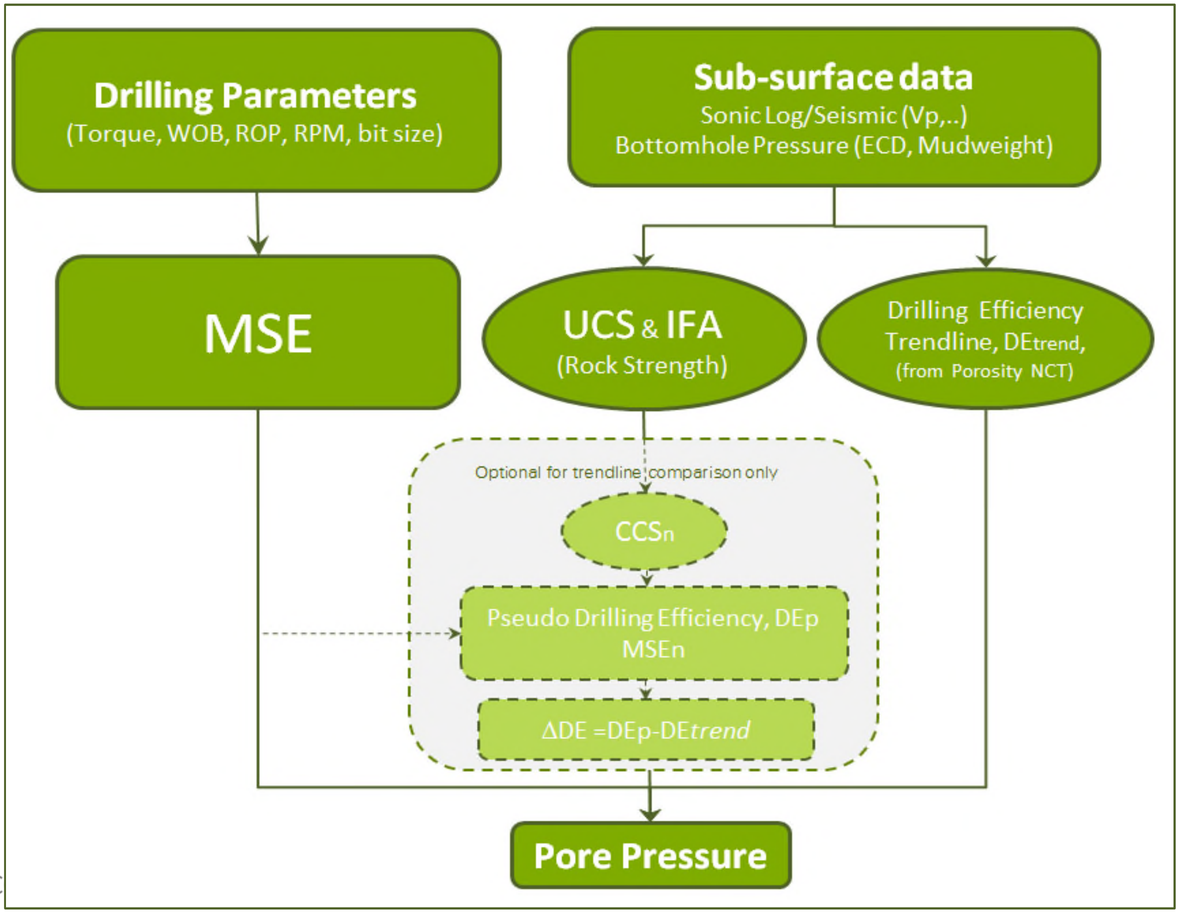
Normal compaction porosity trendline

$$p = ECD - (DE_{trend} \times MSE - UCS) \times \left(\frac{1-\sin\theta}{1+\sin\theta}\right)$$



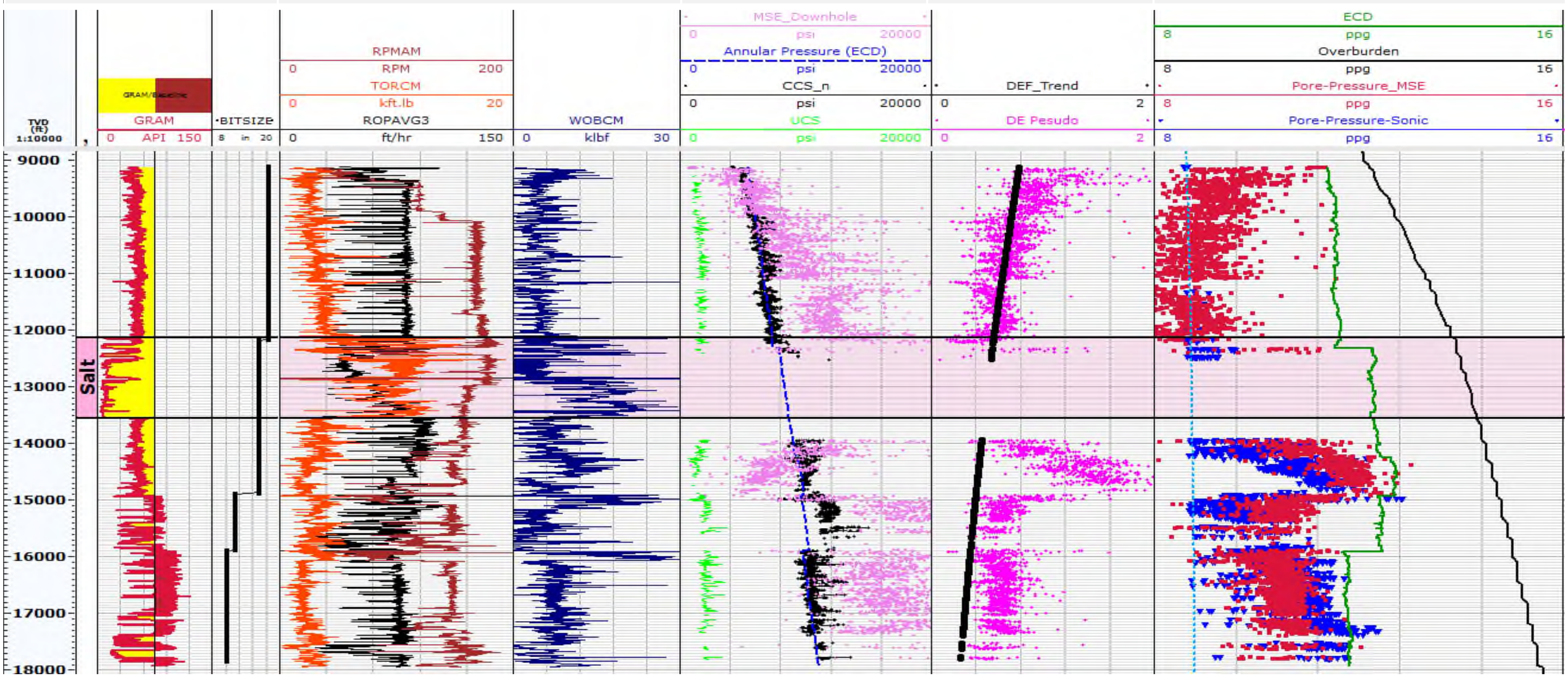
$$p = p_n + \Delta DE \times MSE \times \left(\frac{1-\sin\theta}{1+\sin\theta}\right)$$

Pore Pressure from MSE Work-Flow

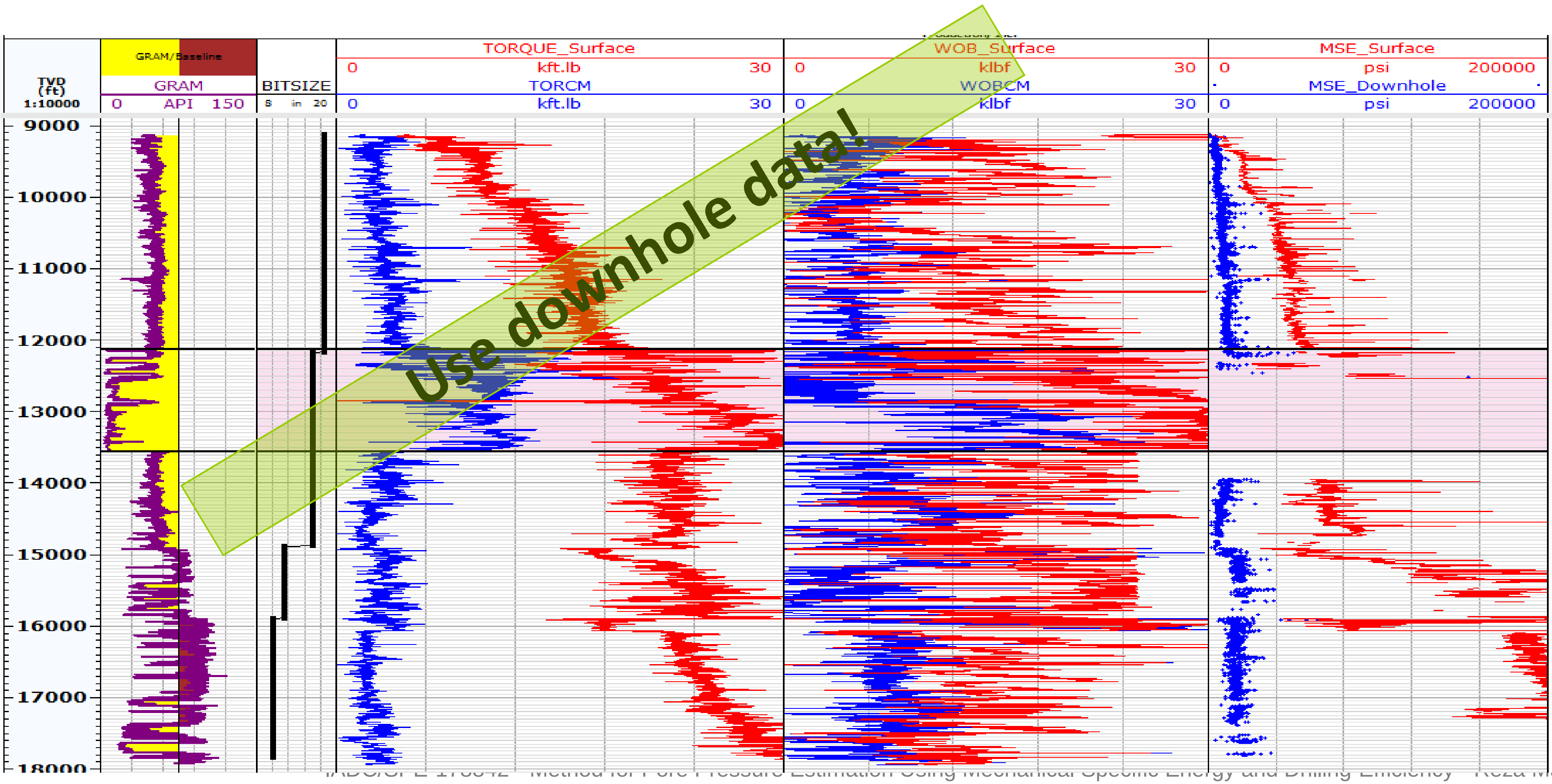


Field Example: Deepwater Gulf of Mexico

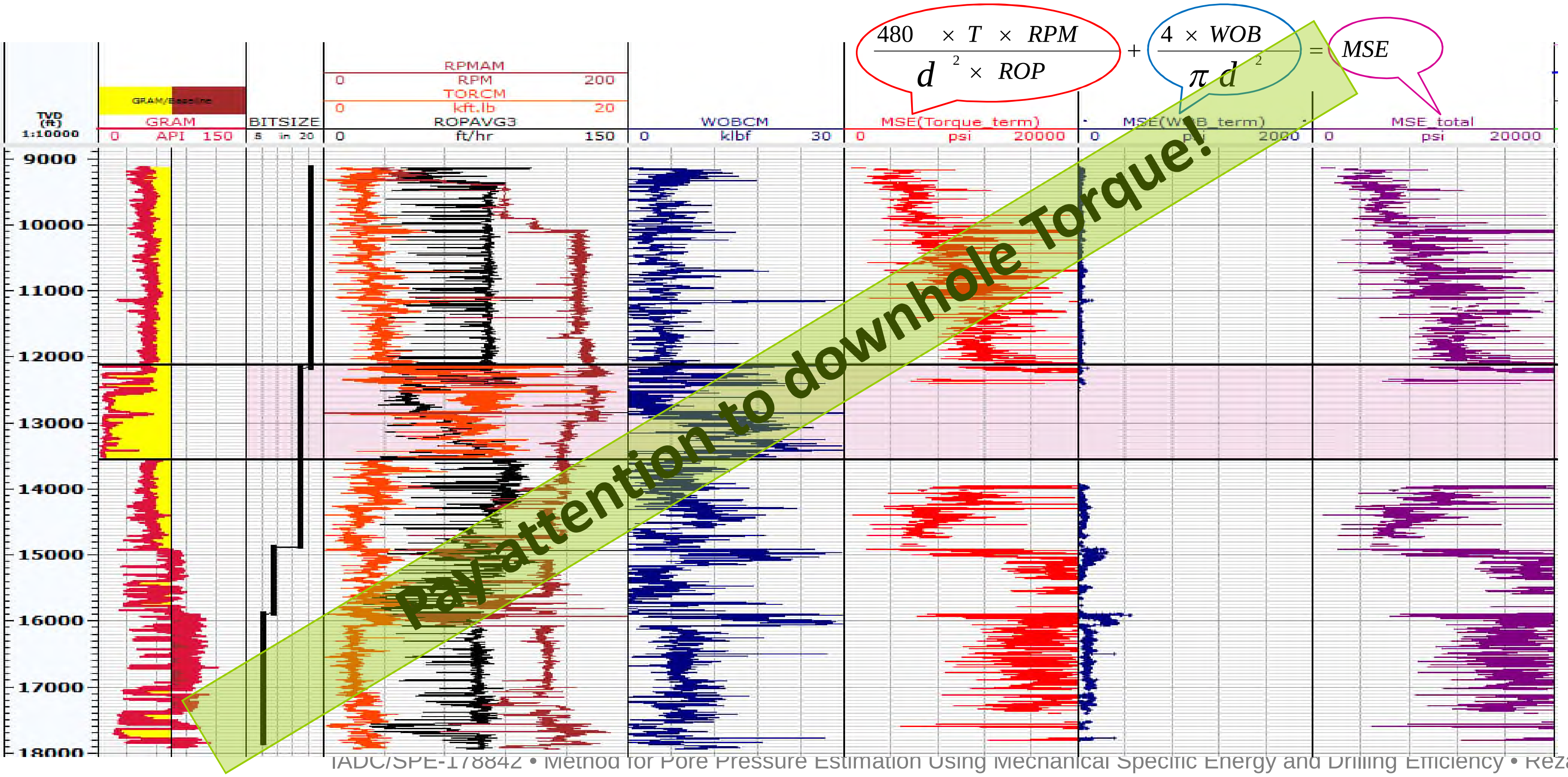
	Drilling Data	MSE & CCS	Drilling Efficiency	Pore Pressure data



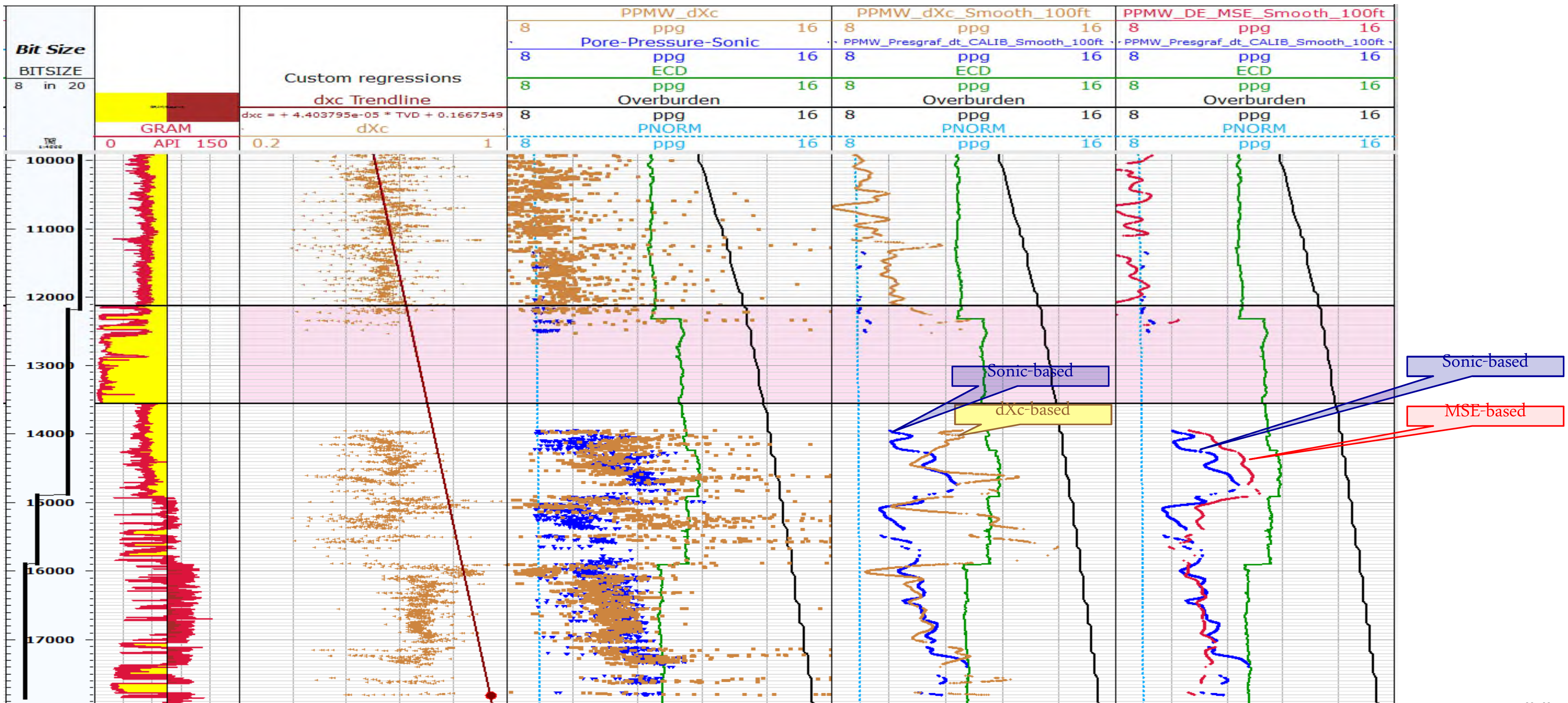
Downhole vs. Surface Data



Torque vs. WOB



d-exponent vs. MSE based Pore Pressure



Final Remarks

- The proposed energy based approach (**MSE-based**) provides new insight into pore pressure estimation from drilling mechanics data (real-time pp detection @ bit).
- **Insitu rock strength** was considered in order to obtain pore pressure from MSE and drilling mechanics data (=>**drilling efficiency**).
- **Downhole data** are recommended to be used for pore pressure estimations. Surface data could be misleading for pore p. estimation.
- Since **Torque @ bit** dominates the MSE, PP estimation is much more sensitive to the **Torque @ bit** rather than **WOB**.
- The **MSE-based** Pore Pressure approach has great advantages over the dXc in terms of reduced subjectivity in the **trend line** and capturing the physics of cutting action by taking into account **torque** and in-situ **rock strength**.

Thank You
Questions?