OVER 80 YEARS OF INNOVATION

D-code™

The key to deciphering your well

Geomechanical Properties, Fracture Identification, and Formation Pressure from Drilling Data

Core Lab®

RESERVOIR OPTIMIZATION

Outline

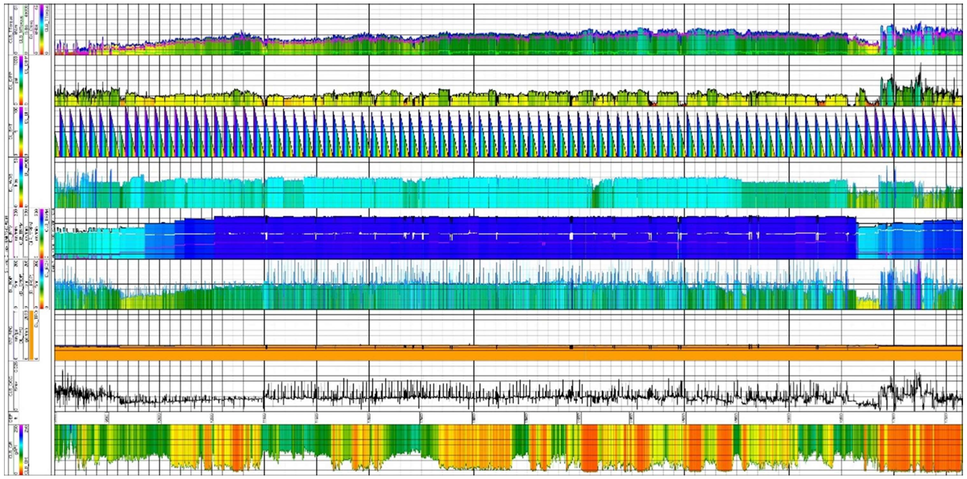
- General Methodology
- Drilling Applications
- Completions Applications
- Summary and Conclusions

General Description

Industry is always looking to do more with less. How can we maximize the use of the massive amounts of data being collected?

- Drilling inefficiencies and complications
- Desire for better subsurface visibility
  - Log coverage, quality, and averaging
  - Limited horizontal logging
- Visualization of events during drilling and/or completions to identify/explain the occurrence and predict and improve performance on future wells

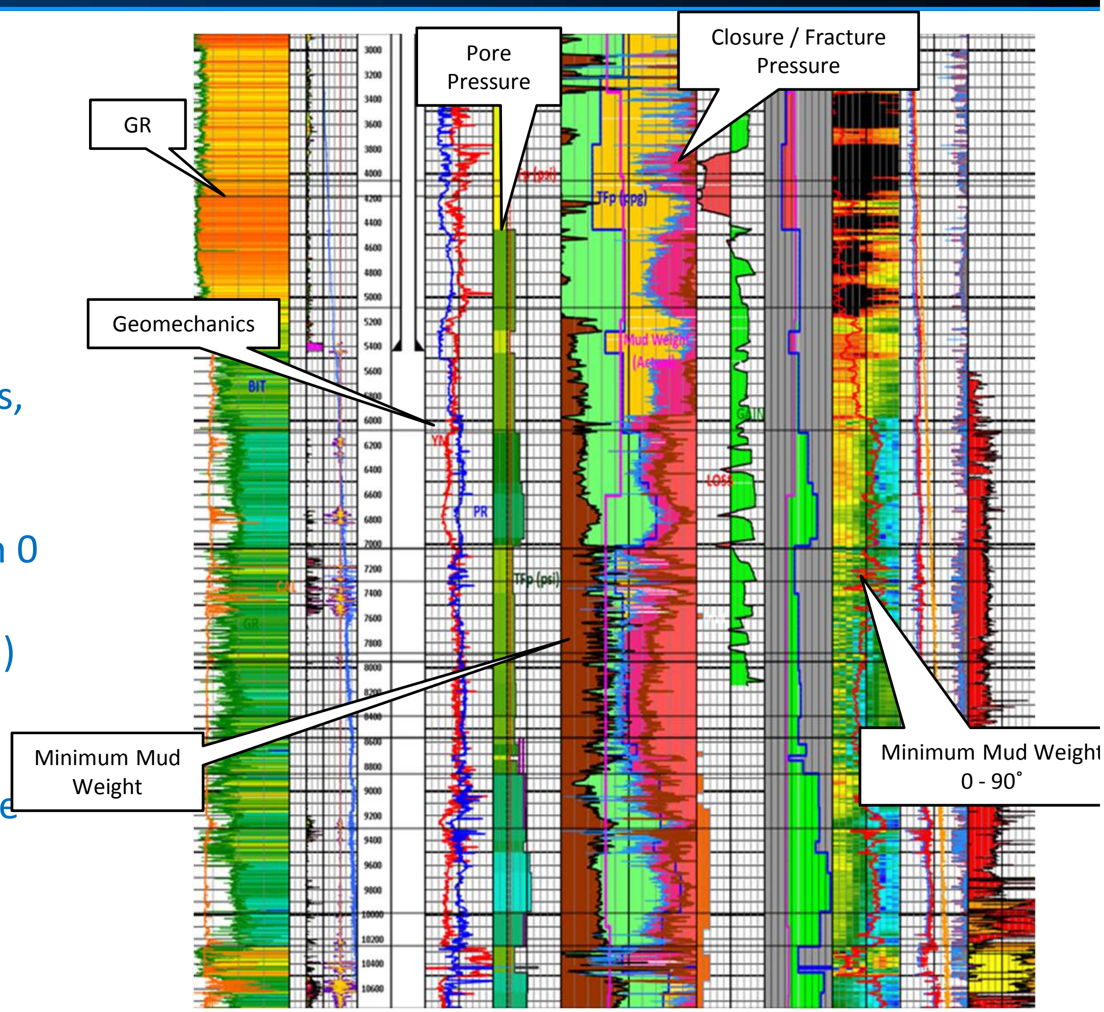
Can this be accomplished with a dataset that all wells have and doesn't increase costs?



General Description

The modeling process results in a core-calibrated reservoir description that provides visibility into a well's geomechanical and pore pressure characteristics utilizing only drilling data

- Outputs
  - High resolution UCS, Young's Modulus, Poisson's Ratio, Brittleness in vertical and horizontal direction
  - Optimized mud weight windows from 0 – 90 degrees
  - Pore pressure (vertical and horizontal)
- Applications
  - Optimized casing points
  - Integration of completions data where available
  - Identification of fractures/faults



Simplified Methodology

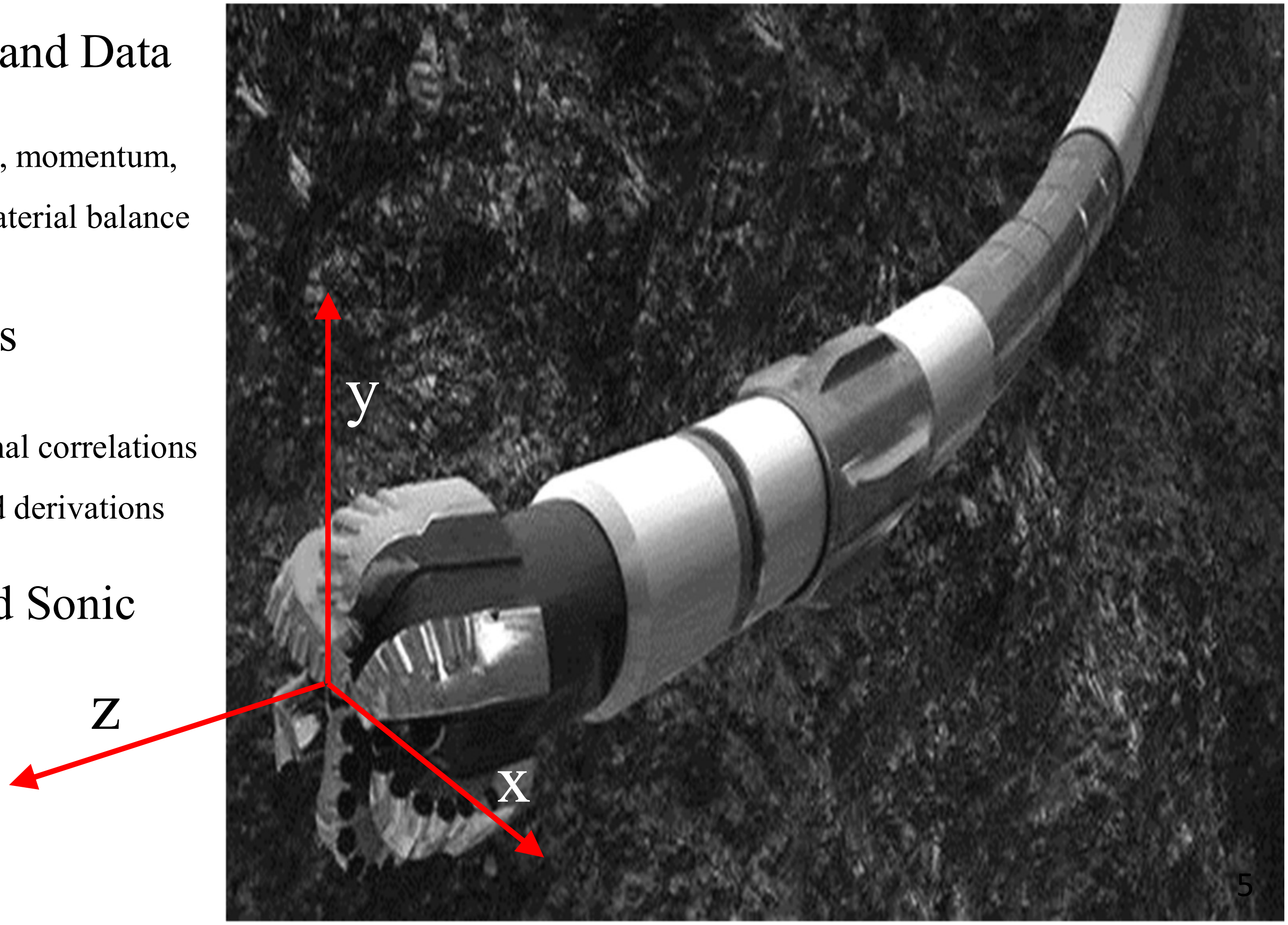
Drilling Parameters and Data

Force, momentum, and material balance

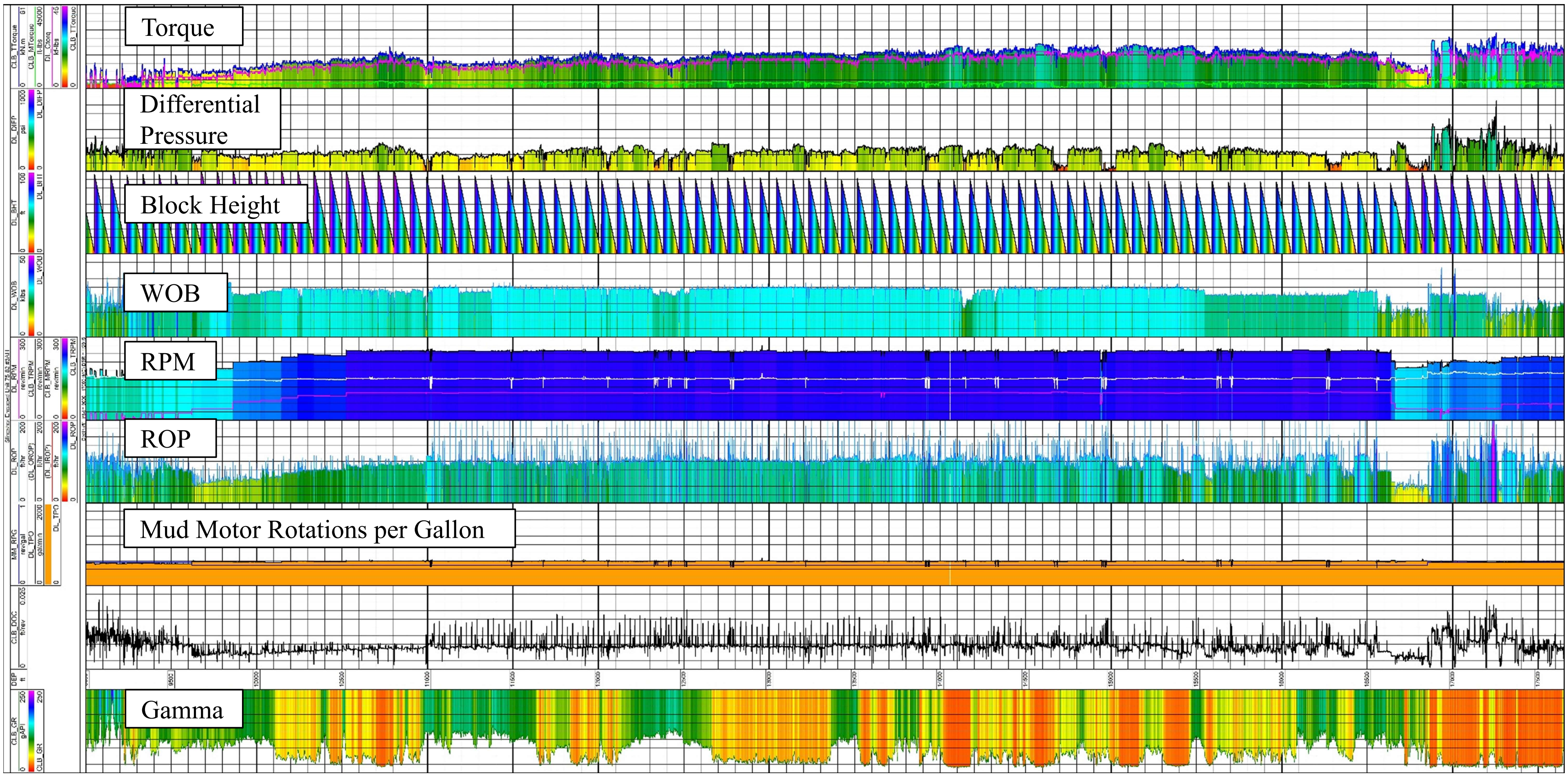
Drilling Forces

Internal correlations and derivations

Rock Mechanics and Sonic Properties



Input Curves



Drilling Forces

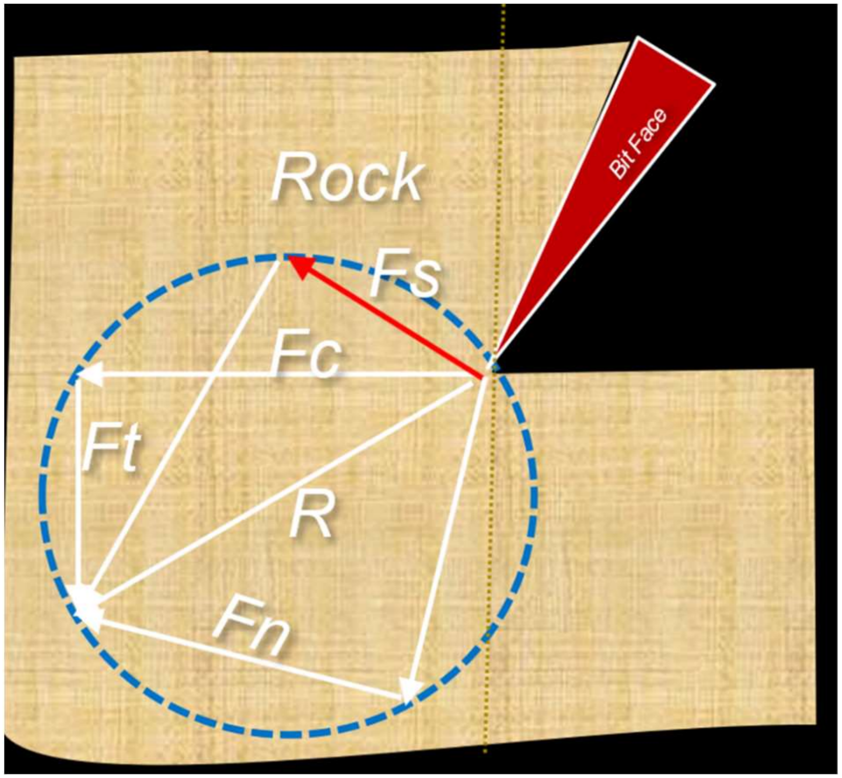
Ft – Tangential Forces = f(WOB, ROP)

Fc – Cutting Force = f(Torque, ROP)

Fs – Shear Force = f(Ft, Fc)

Fn – Normal Force = f(Ft, Fc)

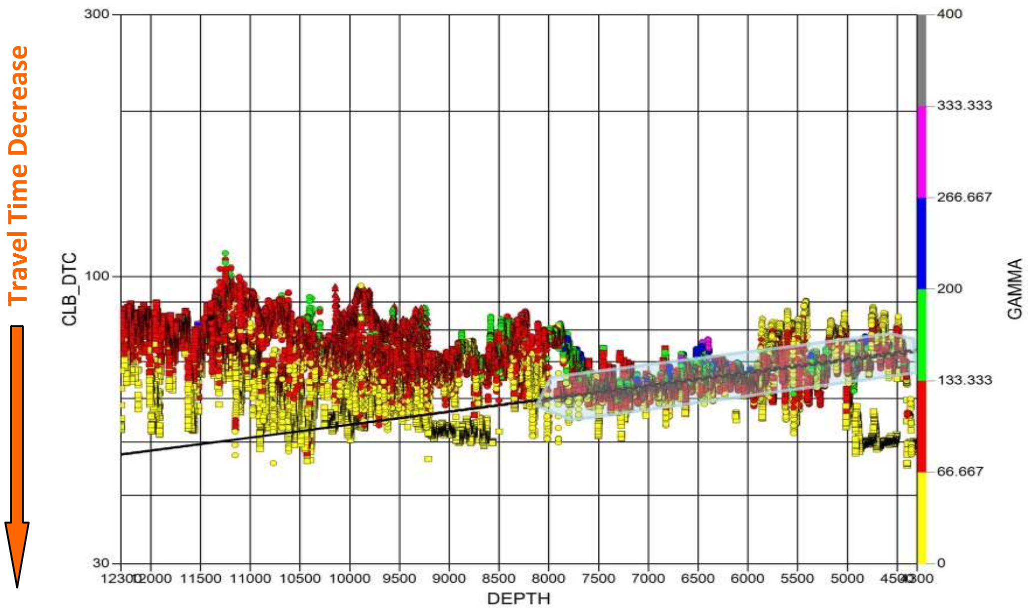
Sonic and Geomechanical Properties are based on core-calibrated relationships between drilling inputs and forces.



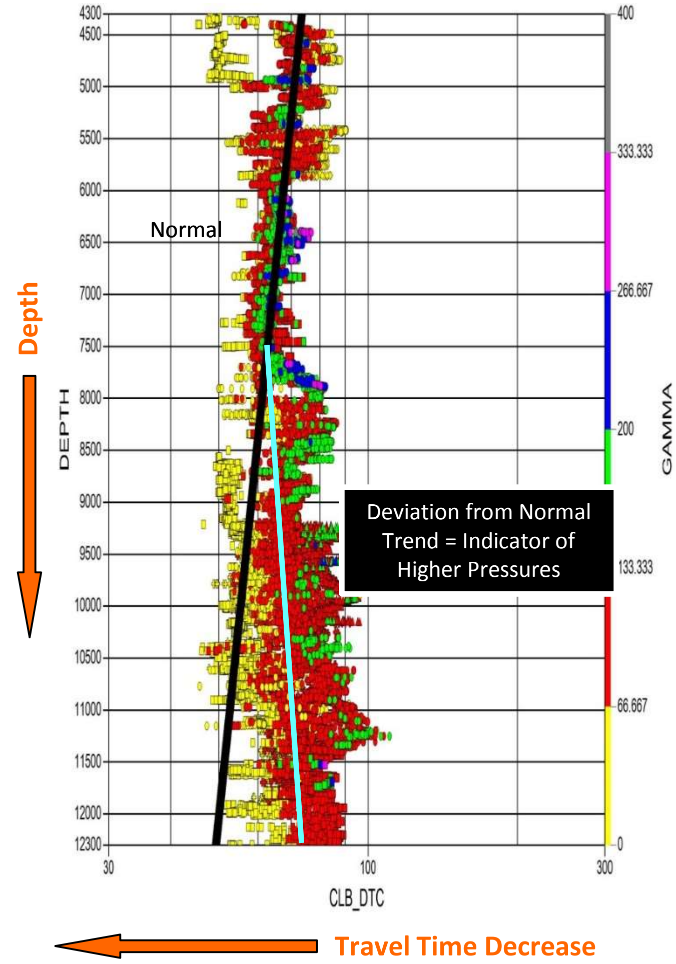
Pore Pressure

- A normal pressure trend from sonic log data shows a reduction of travel time with compaction due to increasing over pressure with depth (Hottman and Johnson).
- The normal pressure trend is determined through comparison of multiple wells throughout the area of study (Reference Example).

Reference Example (Flipped Axis)

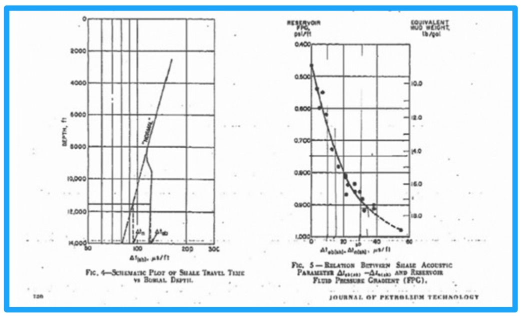


Reference Example

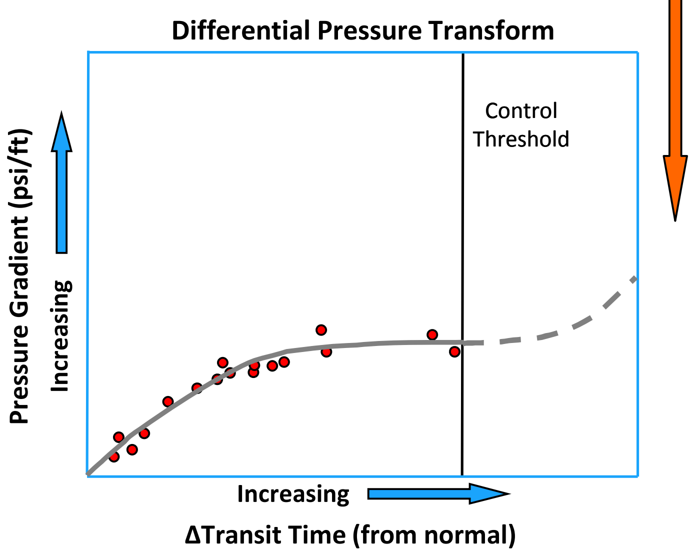


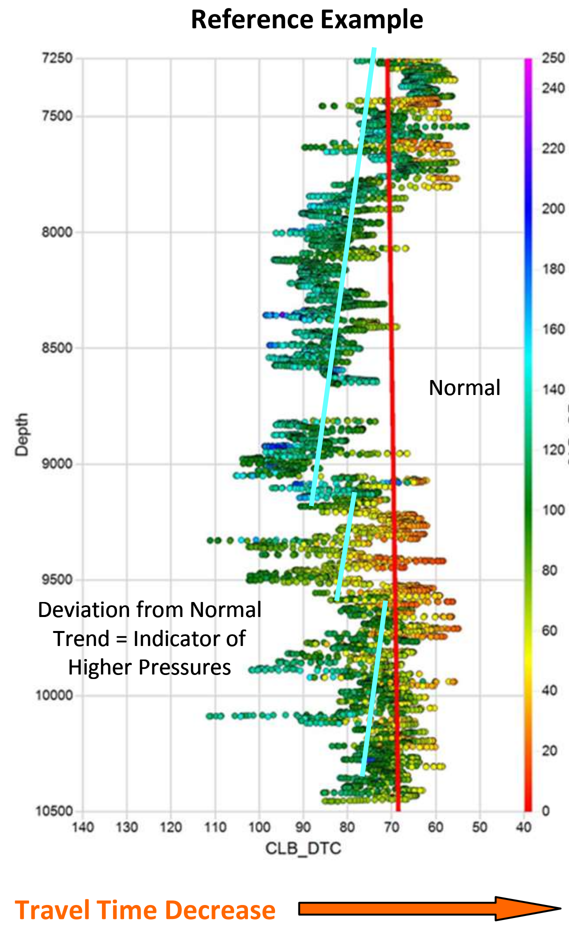
Pore Pressure Modeling –
Pressure Gradient Determination

- An observed travel time curve is compared and quantified based on the normal compaction of shales curve.
- A pressure gradient can then be derived by using the function of the difference in travel time from the normal compaction and published DFIT data.

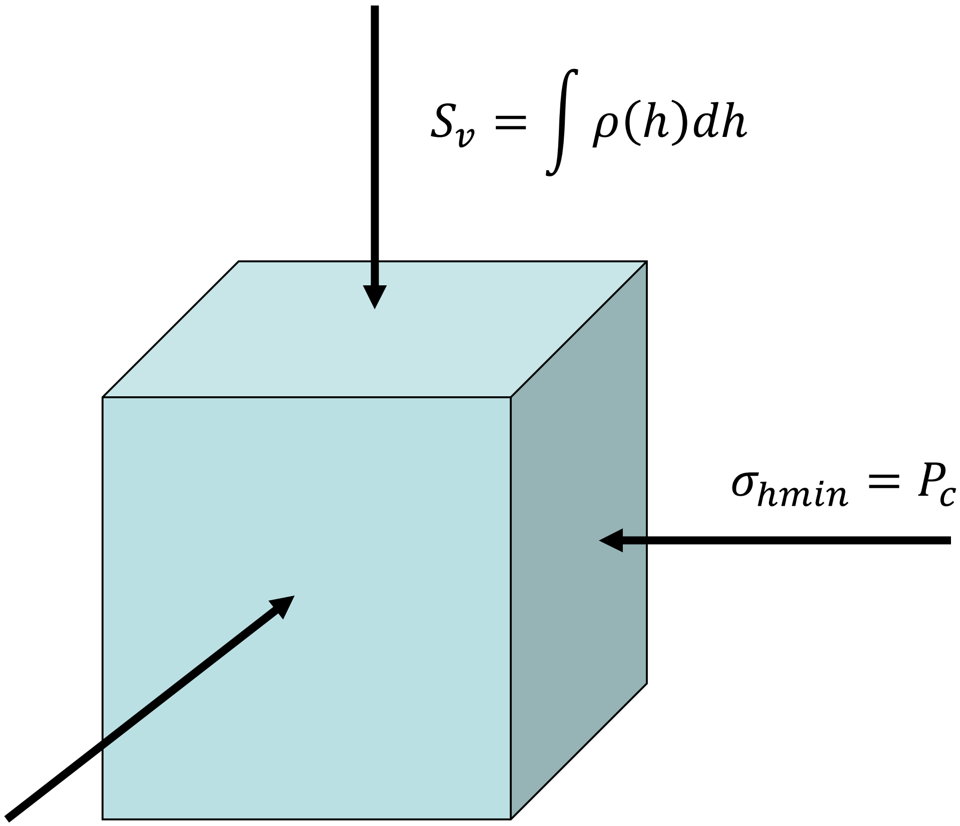


**Estimation of Formation Pressures from Log-Derived Shale Properties, C. E. Hottman and R.K. Johnson*





Principle Stresses

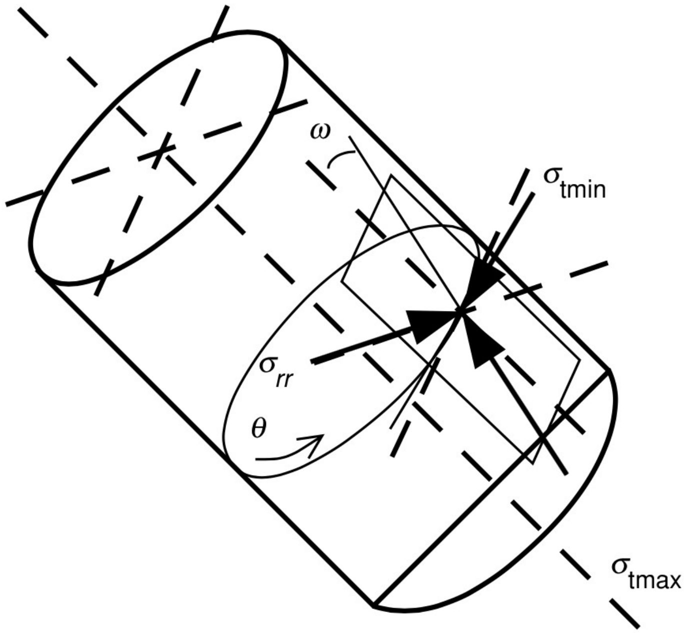


$$S_v = \int \rho(h)dh$$

$$\sigma_{hmin} = P_c = \frac{\upsilon}{1-\upsilon} * (\sigma_v - P_p) + P_p + \varepsilon * E$$

$$\sigma_{hmax} = \sigma_{hmin} + Stress\ Anisotropy$$

Principle Effective Stresses



$$\sigma_t\max = \frac{1}{2}\left(\sigma_{zz} + \sigma_{\theta\theta} + \sqrt{(\sigma_{zz} - \sigma_{\theta\theta})^2 + 4\tau_{\theta z}^2}\right)$$

$$\sigma_t\min = \frac{1}{2}\left(\sigma_{zz} + \sigma_{\theta\theta} - \sqrt{(\sigma_{zz} - \sigma_{\theta\theta})^2 + 4\tau_{\theta z}^2}\right)$$

Reservoir Geomechanics. Zoback. 2007

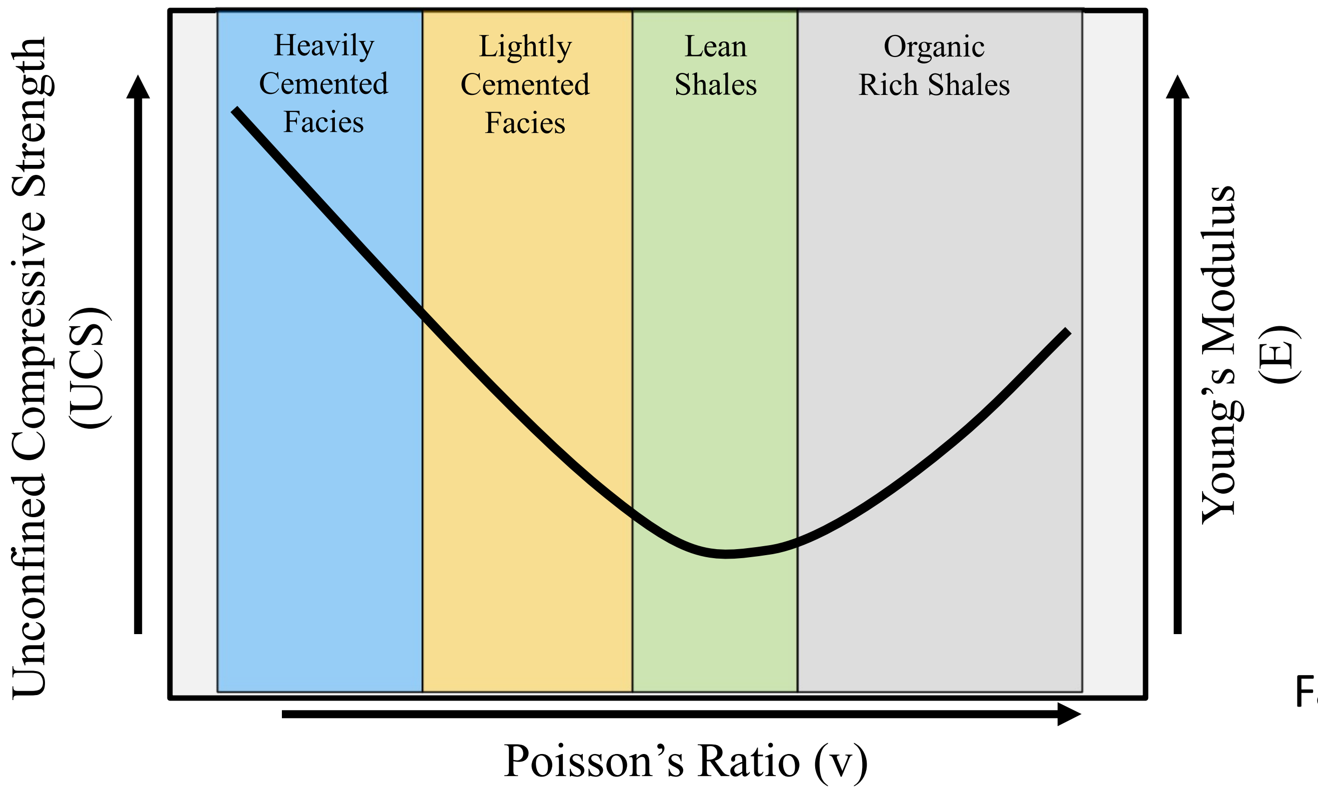
Minimum Mud Weight

$$F = (\sigma_c + q * \sigma_3) - \sigma_1$$

Failure occurs when F < 0

Determination of a safe mud window and analysis of wellbore stability to minimize drilling challenges and non-productive time. Aslannezhad, Manshad, Jalalifar 2015

Controls on Minimum Mud Weight



UCS = f(YM,PR,PP)

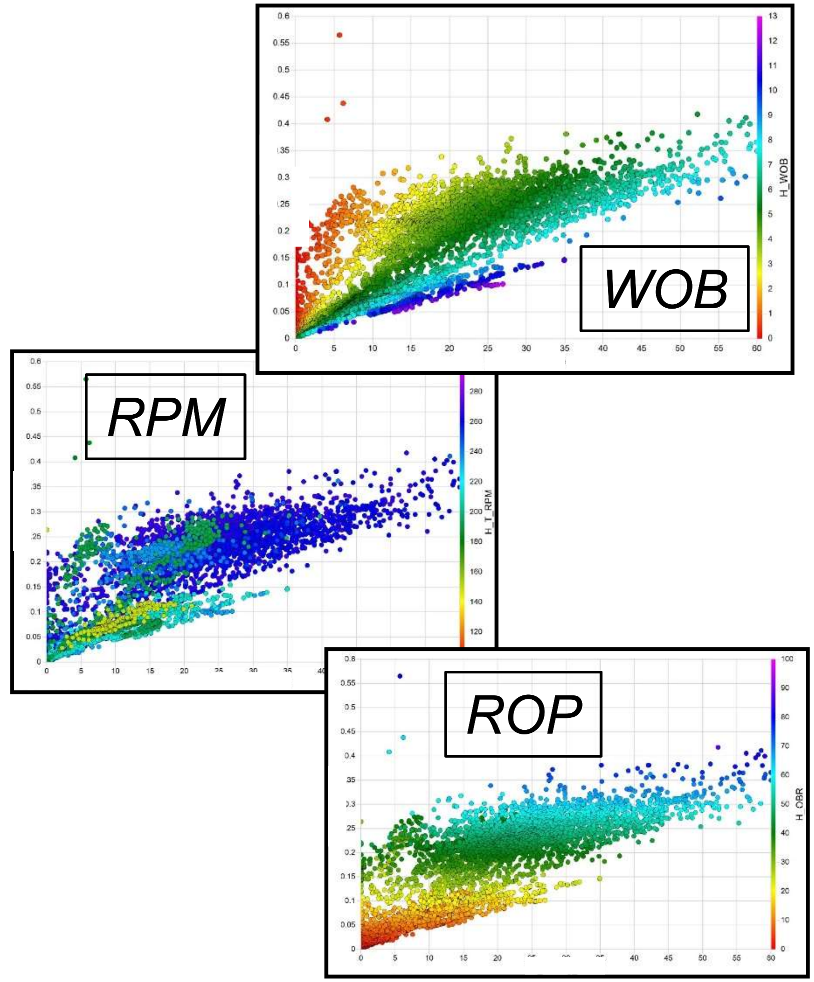
<u>Minimum Mud Weight</u>

$$F = (\sigma_c + q * \sigma_3) - \sigma_1$$

Failure occurs when F < 0

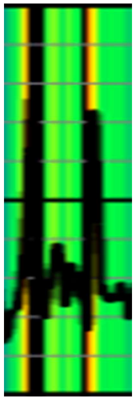
Optimized Drilling Parameters

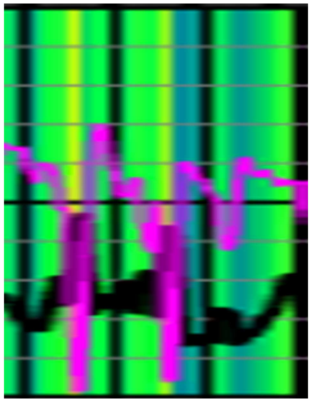
- Operator was consistently facing issues with bit jamming and complete loss of wellbore
- By comparing the mechanical properties, efficiency parameters, and force parameters the following was determined:
  - Optimized weight on bit
  - Optimized revolutions per minute
  - Minimum mudweight necessary
- With these parameters, they were successful in their drilling while not losing time due to increased mudweight



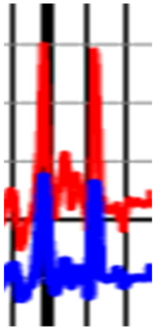
Fracture Indicators

- Sharp increases in modeled brittleness result from a change in torque read by the drilling rig

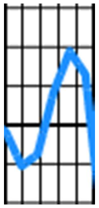




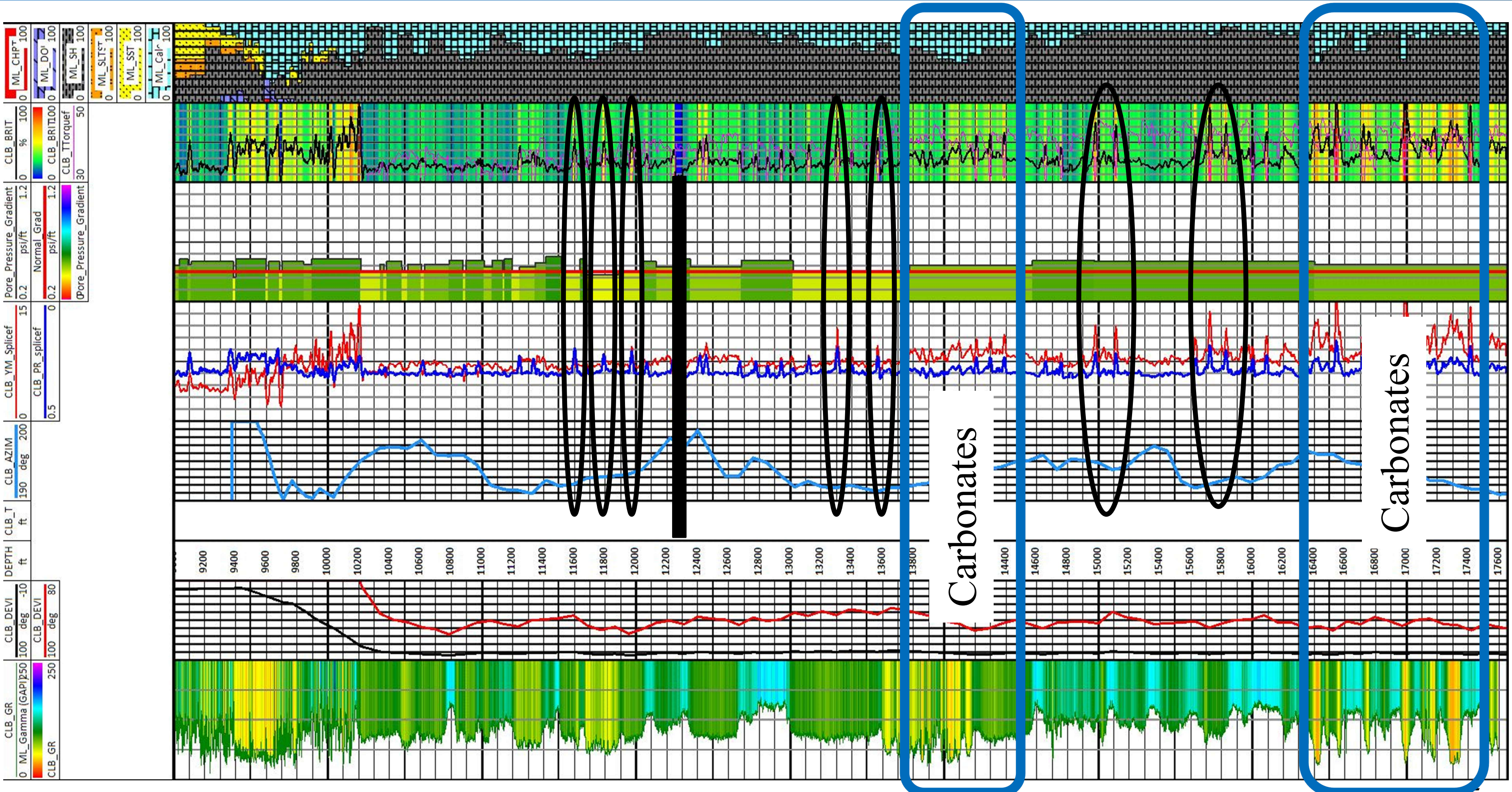
- Calculated Young's Modulus and Poisson's Ratio will show similar spikes



- Running across these fractures can often cause changes in azimuth to occur

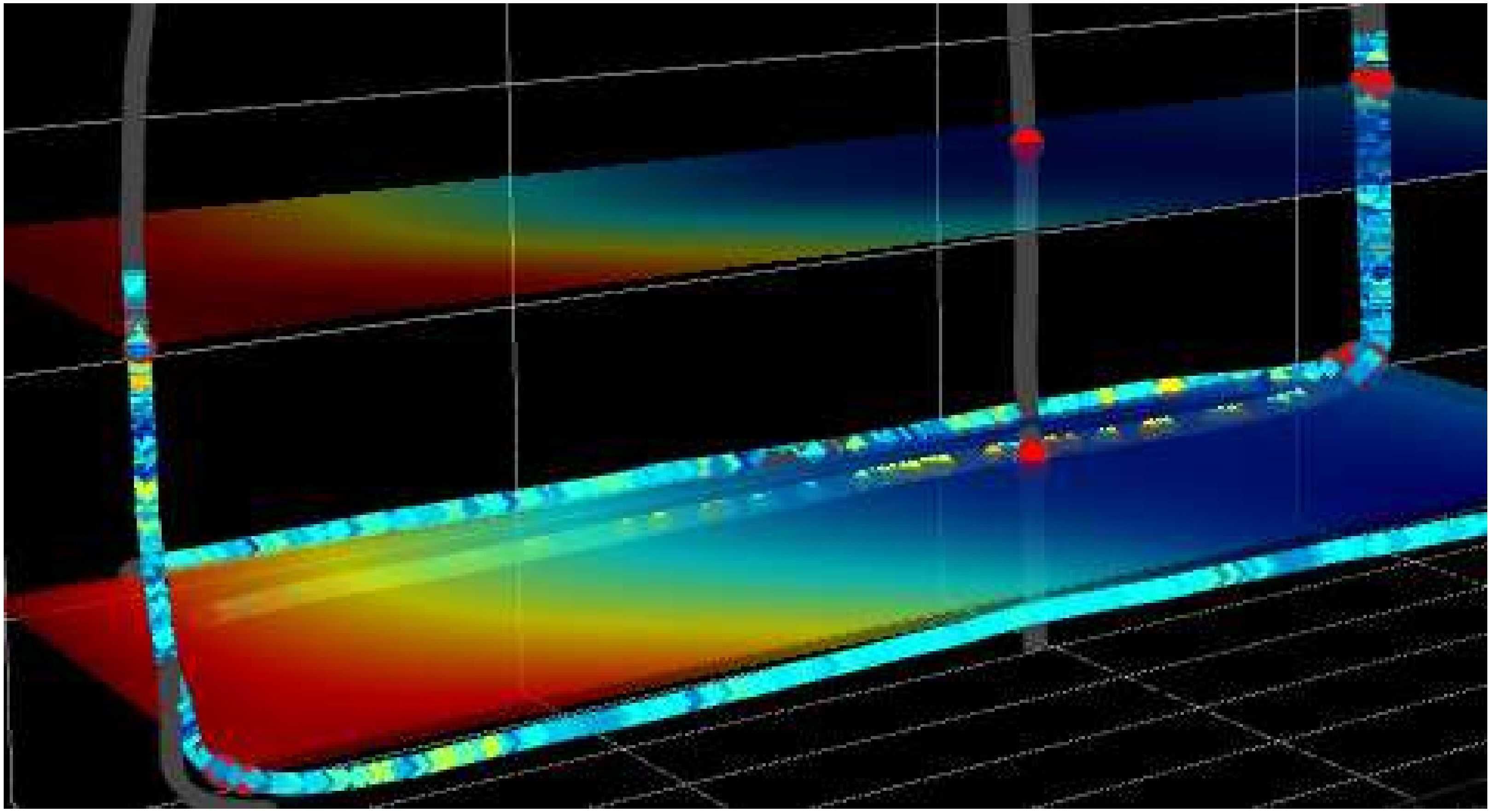


Fracture Indicators



Full Integration

3D Brittleness View



Conclusions

- The drilling data provides a rich dataset for investigation. Through careful correlations and calculations, this data can be used to derive geomechanical properties of the reservoir being penetrated.
- Continued derivations provide estimates of rock failure criteria and fracture pressures.
- When combined with broader reservoir understanding, these models can be used to optimize drilling and completions procedures.
  - Specific signatures have been identified for fractures along the wellbore.
  - Persistent application of the model in a reservoir can also allow for identification of specific common rock fabrics and geological features.

Thank you!