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Why Drillers Need Logs More Than You Think

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Outline

- Why Driller's traditionally despise Logs
- Why Driller's should want Logs
- 6 Steps to Build a Mechanical Earth Model from Logs
- Conclusions

Top 4 Reasons Drillers Don’t Like Logs

1. **Logs cost money** - management often makes $/ft our #1 directive
2. **Logs (wireline) take time** - see #2 (time=money)
3. **Logs expose us to more risk** - RST=Repeat Sticking Tool
4. **(Lack of) Communication** – The root of most evil
   - the industry has done a poor job articulating the value of logs for/to drillers
   - ϕ, s_w, s_o, k, α, R_w – might as well be a foreign language because they don’t directly affect us
   - Service companies usually put a G&G person in front of the Drillers, who speaks in Communist units and is more interested in the rocks than the implications for Drillers

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Why Drillers Should Want Logs

Estimates of Geomechanics Related Costs

- 41% of Drilling NPT is due to WBS – Dodson
- $8 Billion per year – Halliburton and Shell
- 10% of total well cost - ExxonMobil
- $6.4 Billion per year – Western Atlas
- $1 Billion per year - BP (pre-Macondo)
- >>>$1 Billion per year – BP (post-Macondo)

Drilling Applications

1. Avoid Kicks
2. Avoid Lost Circulation
3. Prevent stuck pipe
4. Avoid sidetracks
5. Improve ROP

Hidden benefit, not captured in industry NPT estimates.

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3 Tiers of Drilling Engineers

1. **Mild** – Doesn't calculate PP/FG. Expects someone else to provide it. Blames problems on "rotten shale" or an "Indian Burial Ground"

2. **Medium** – Calculates PP/FG using seismic, sonic, resistivity, or dx using the Eaton equation (or similar)

3. **Spicy** – Builds their own Mechanical Earth Model from logs. Calibrates model and uses output to design trouble-free wells

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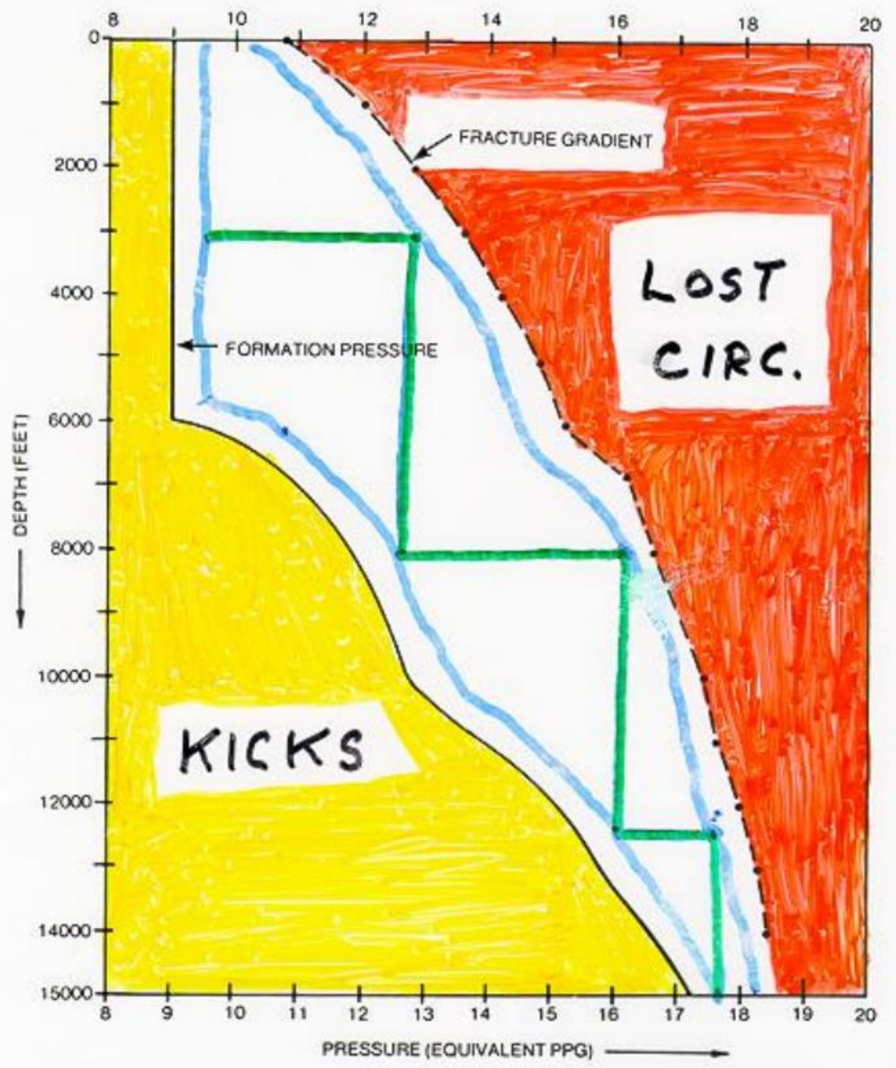
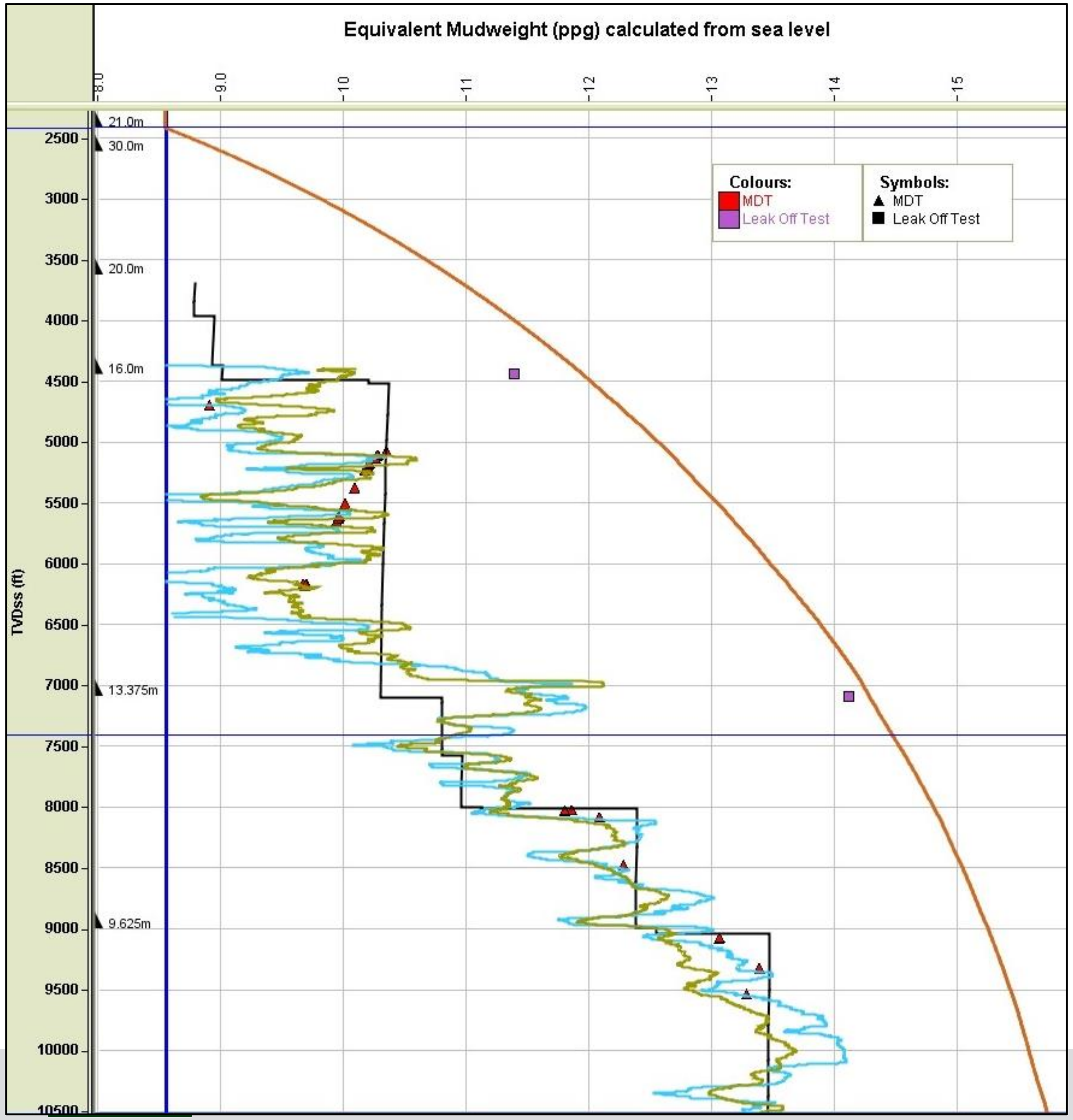
Mild Drilling Engineering



Projected formation pressures and fracture gradients

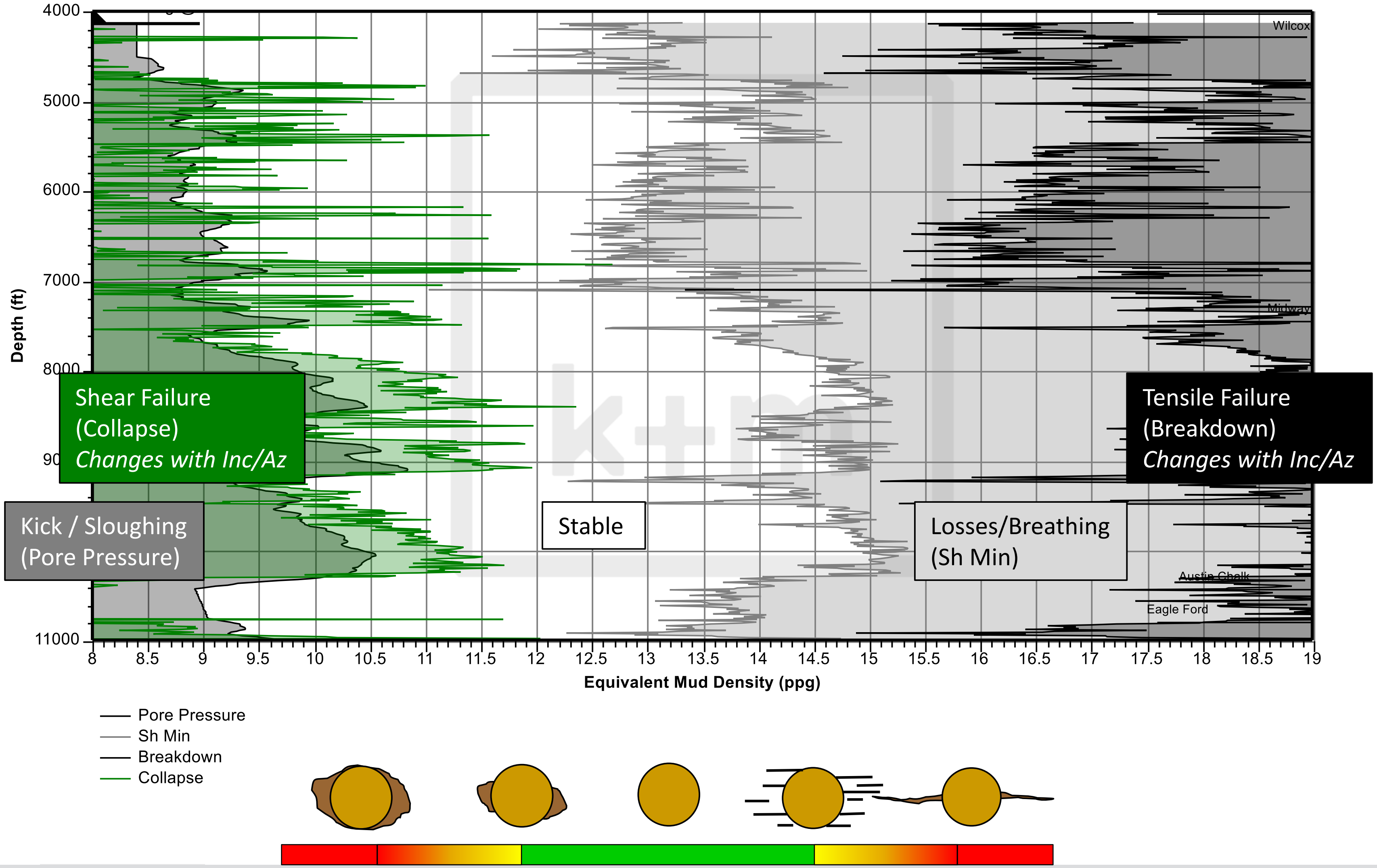
- In most wells the PP/FG is not calculated, especially in a developed area
  - "Pressures are known"
  - "We didn't have problems on the last well"
  - "That's more of an offshore thing"
- Instead, we often make something up, often based on "experience"

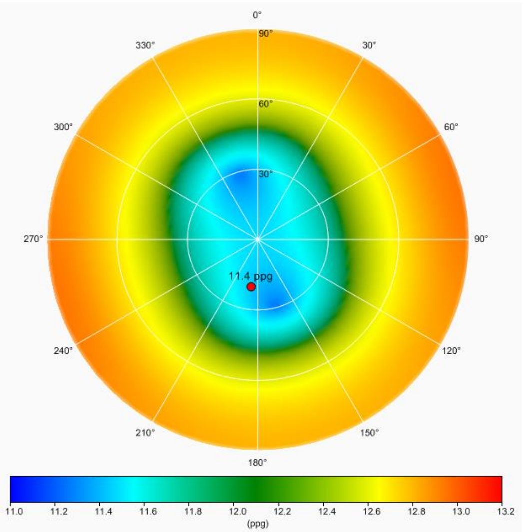
Medium Drilling Engineering (Predicted PP/FG)

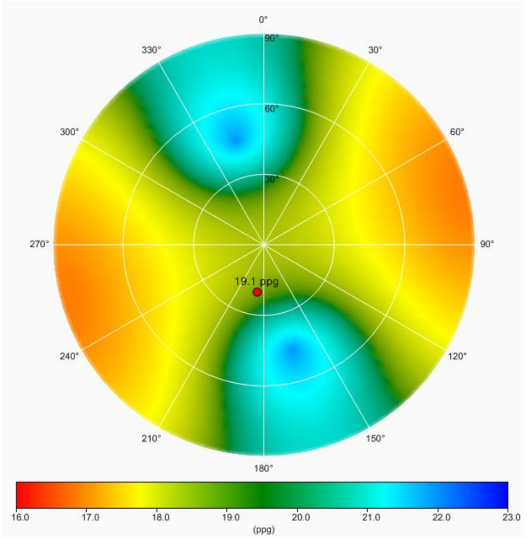


- Predicting pore pressure from seismic, sonic, and/or resistivity is common in offshore settings (especially exploration)
- The fracture gradient can be approximated PP and the overburden
- Turns out, the same techniques can be applied *onshore*…
- …but we needn't stop there…

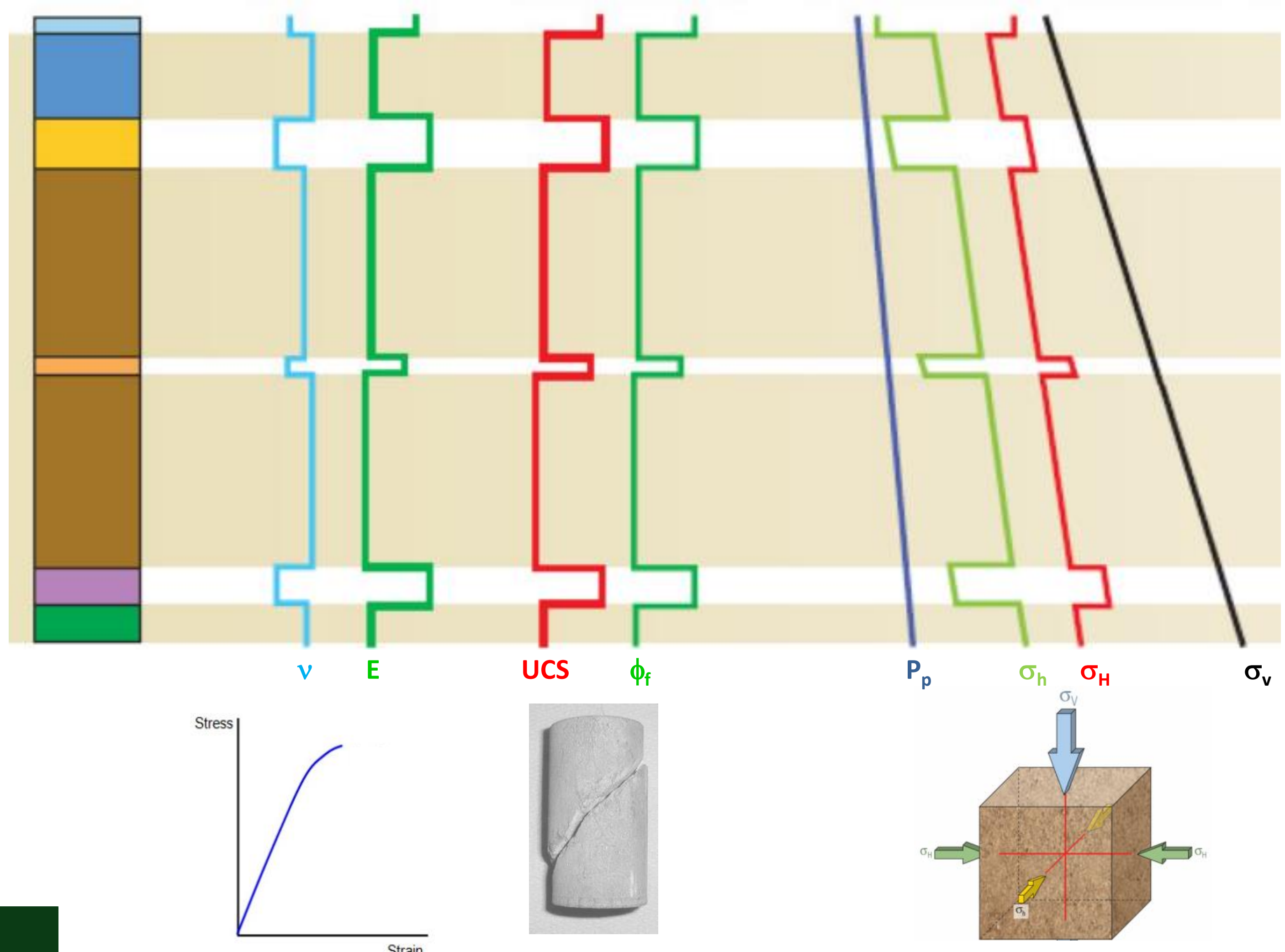
Spicy Drilling Engineering (Full MEM)







What is a Mechanical Earth Model (MEM)?

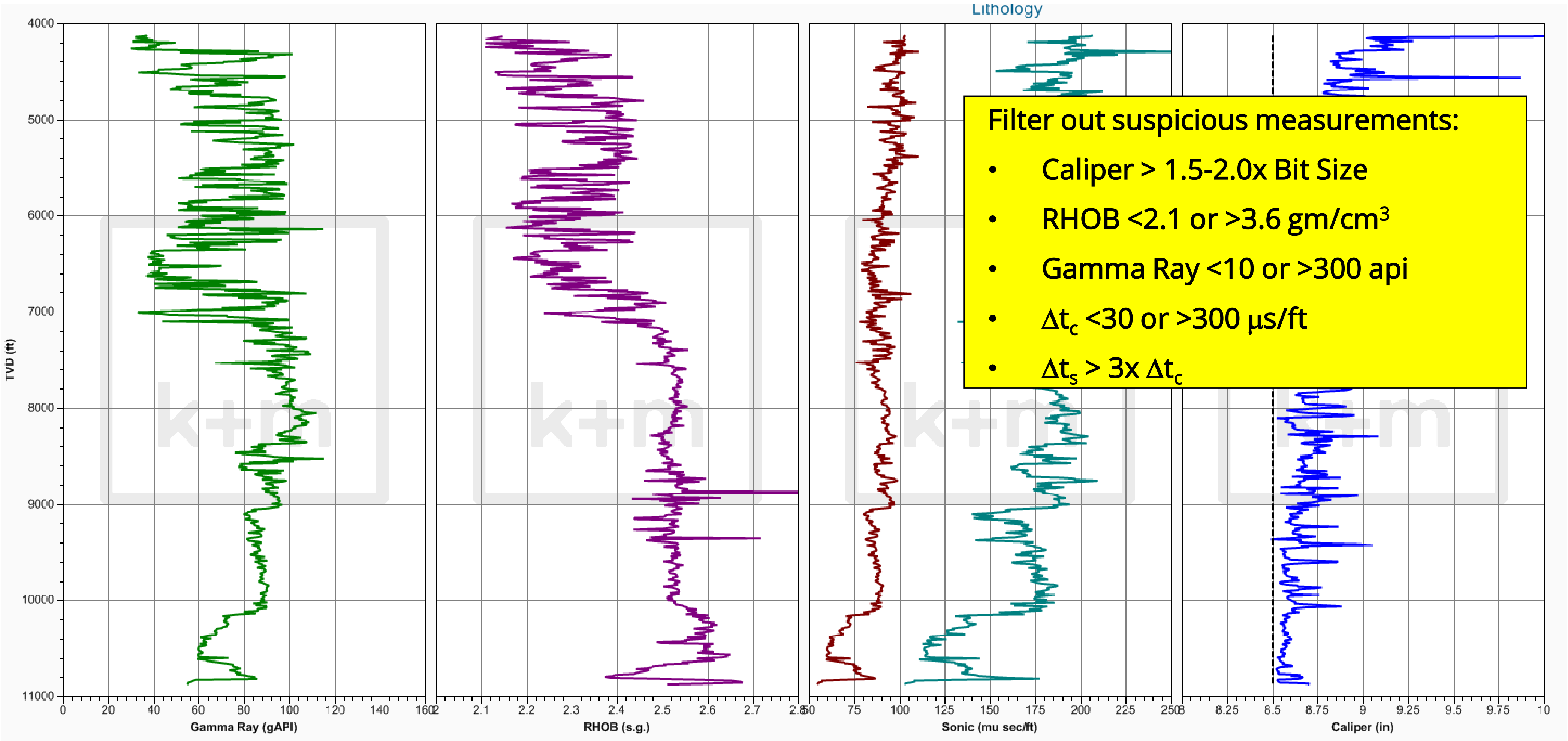


1. **Elasticity:** E, ν
2. **Strength:** UCS, ϕ_f
3. **Stress:** σ_v, σ_H, σ_h, P_p

"All models are wrong, but some are useful."

- George Box, 1976

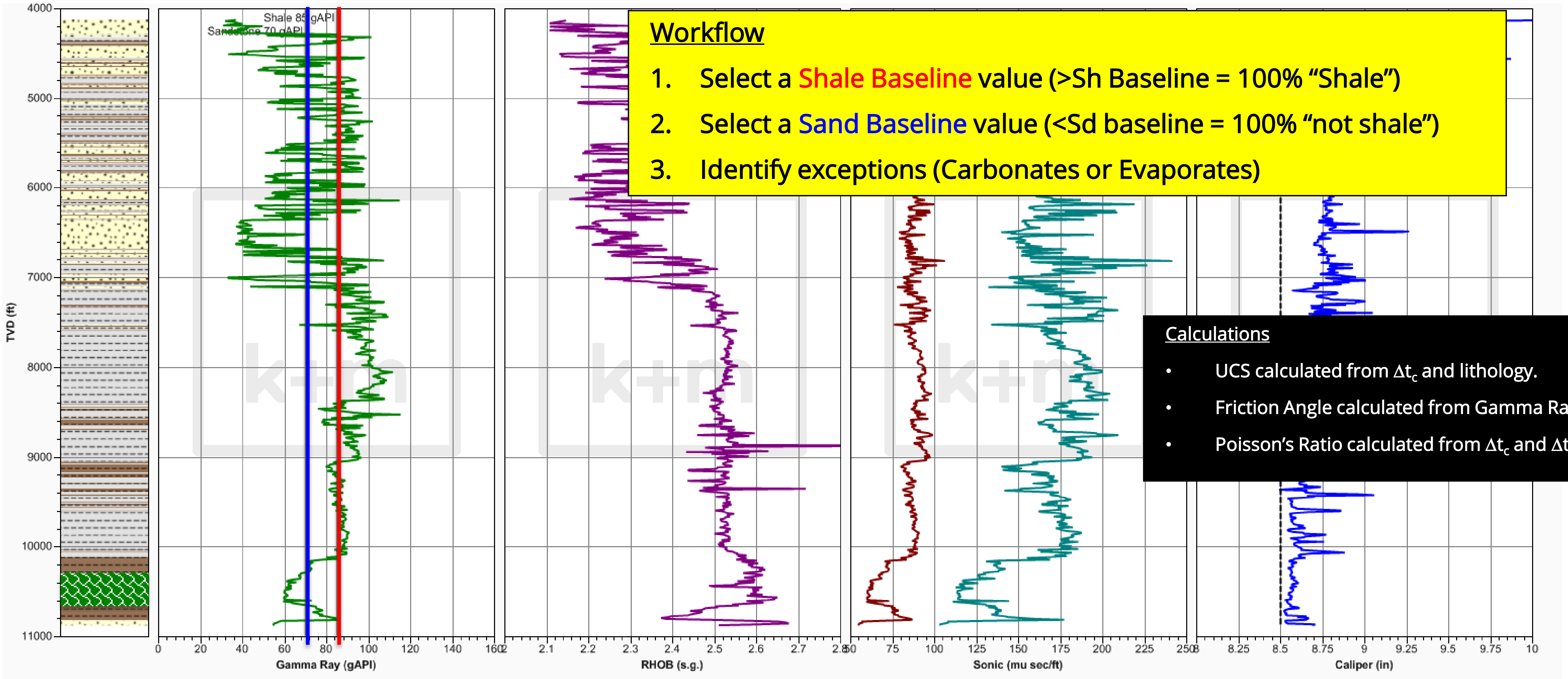
Step 1: QC Logs



Filter out suspicious measurements:

- Caliper > 1.5-2.0x Bit Size
- RHOB <2.1 or >3.6 gm/cm^3
- Gamma Ray <10 or >300 api
- Δt_c <30 or >300 µs/ft
- $\Delta t_s > 3x \Delta t_c$

Step 2: Determine Lithology (Gamma Ray)



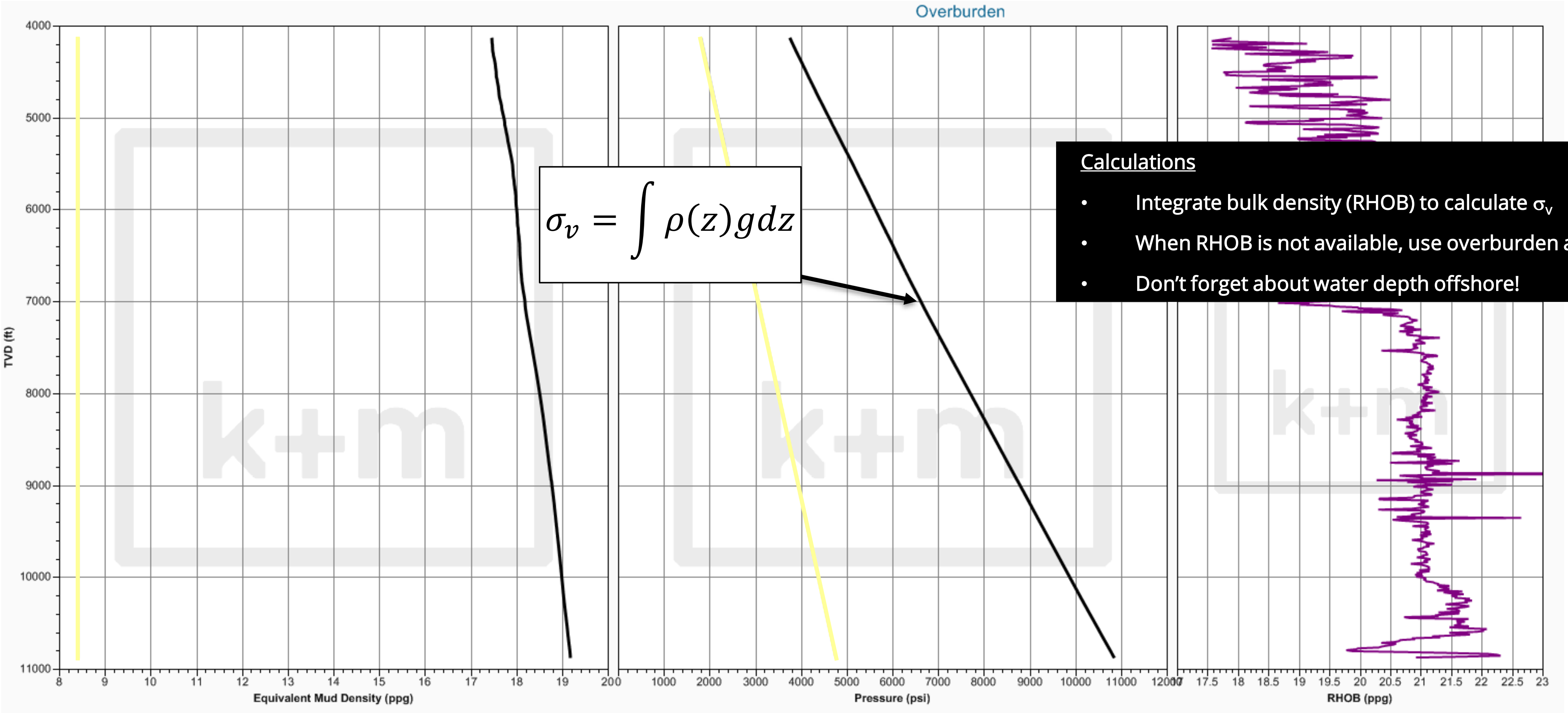
<u>Workflow</u>

1. Select a Shale Baseline value (>Sh Baseline = 100% "Shale")
2. Select a Sand Baseline value (<Sd baseline = 100% "not shale")
3. Identify exceptions (Carbonates or Evaporates)

<u>Calculations</u>

- UCS calculated from Δt_c and lithology.
- Friction Angle calculated from Gamma Ray
- Poisson's Ratio calculated from Δt_c and Δt_s

Step 3: Calculate σ_V / Overburden (Bulk Density)



$$\sigma_v = \int \rho(z) g dz$$

<u>Calculations</u>

- Integrate bulk density (RHOB) to calculate σ_V
- When RHOB is not available, use overburden algorithms
- Don't forget about water depth offshore!

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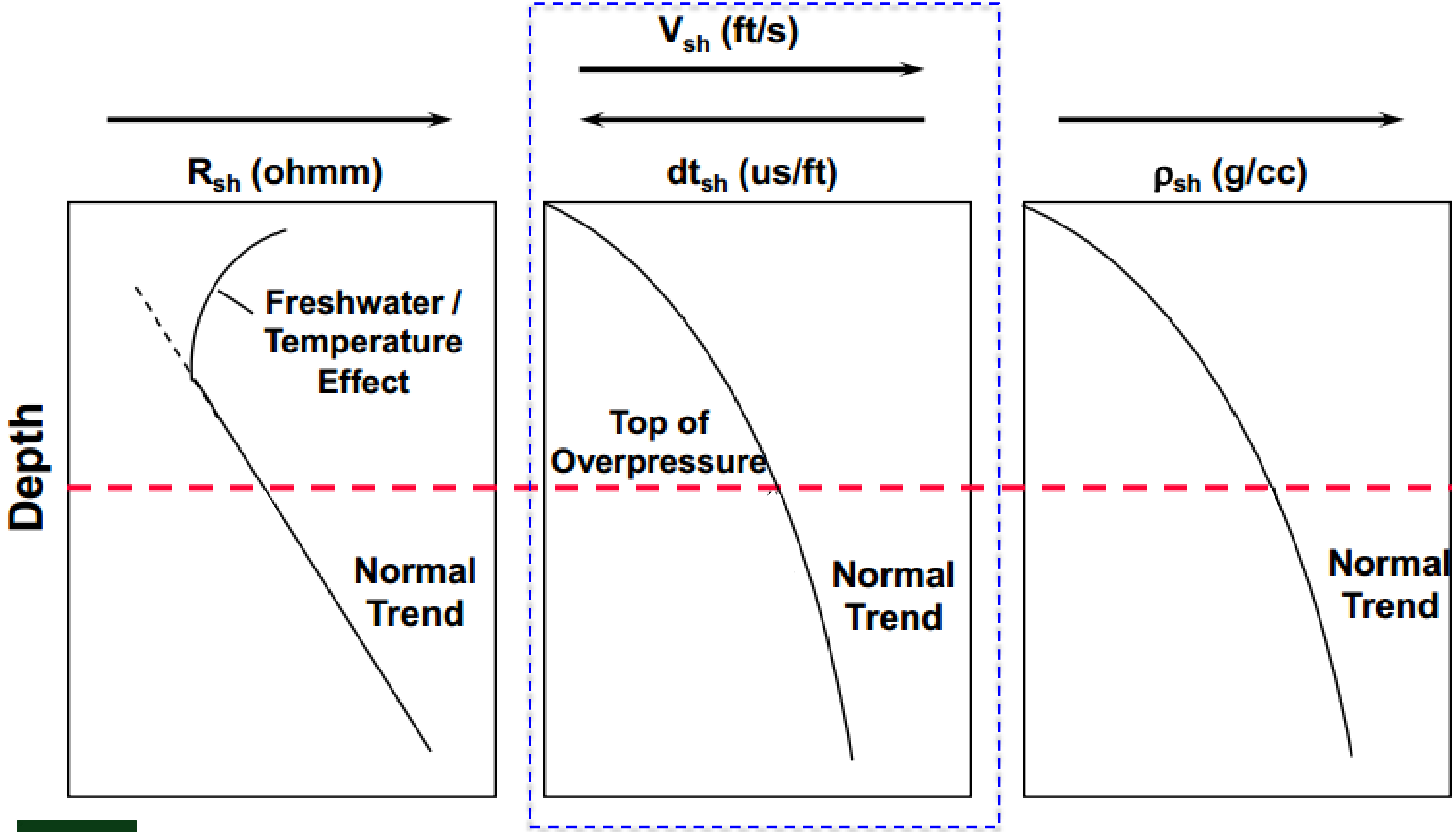
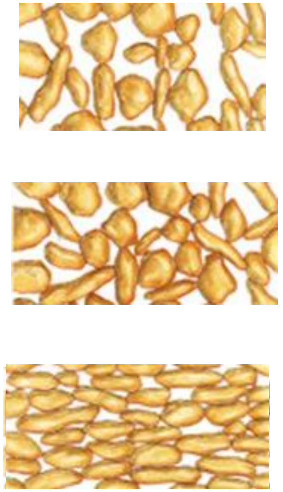
Step 4: Calculate Pore Pressure (Sonic)





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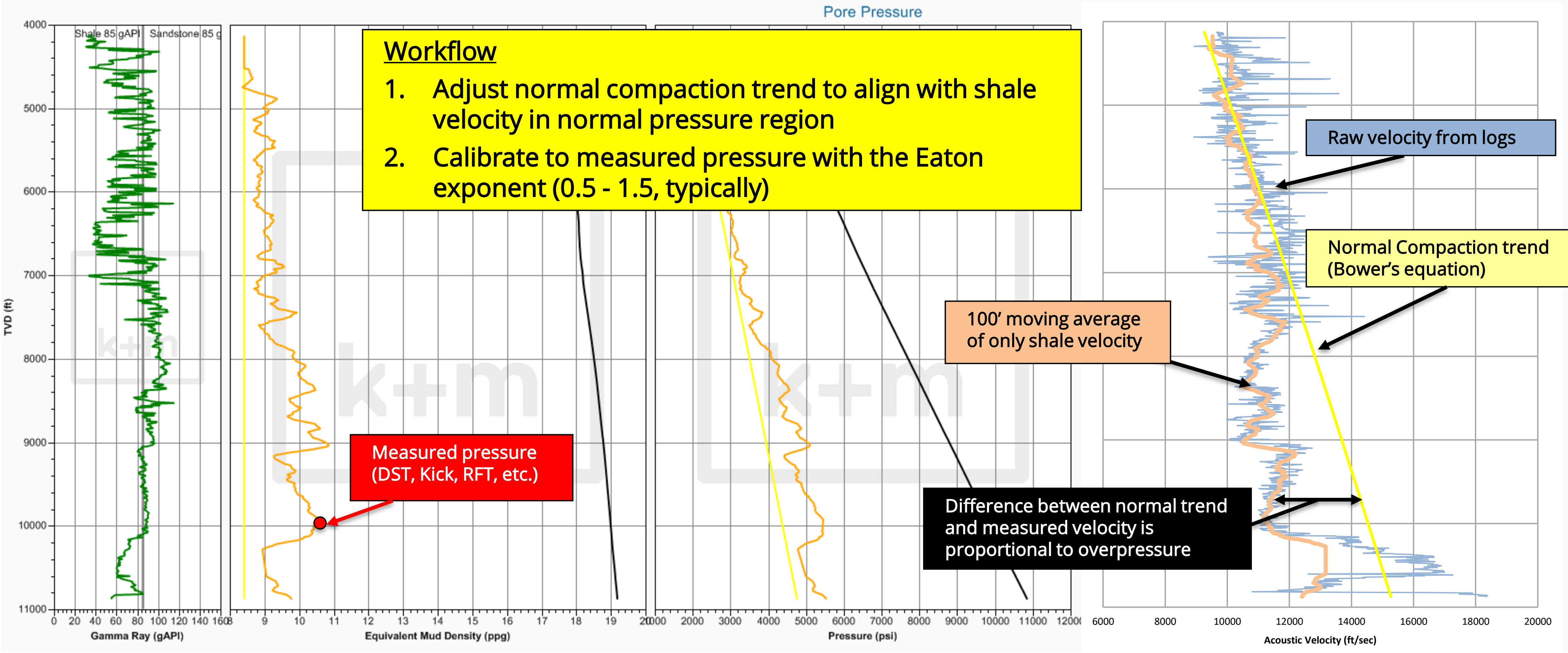
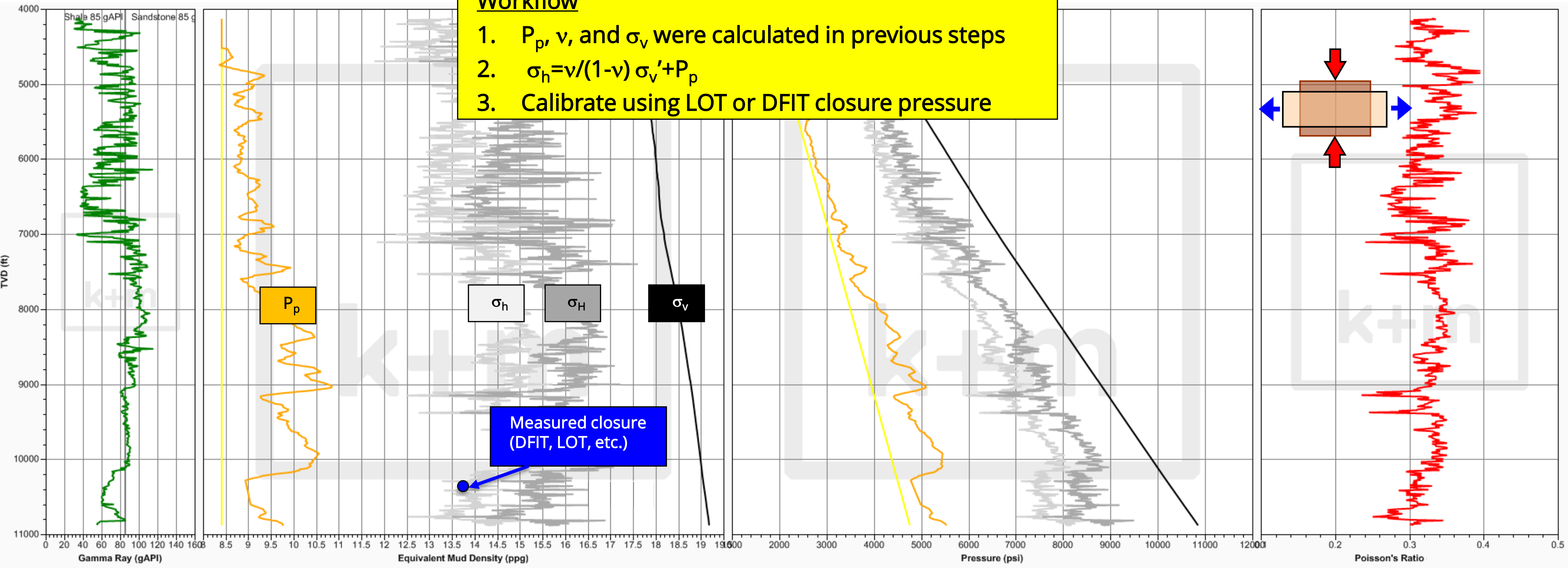


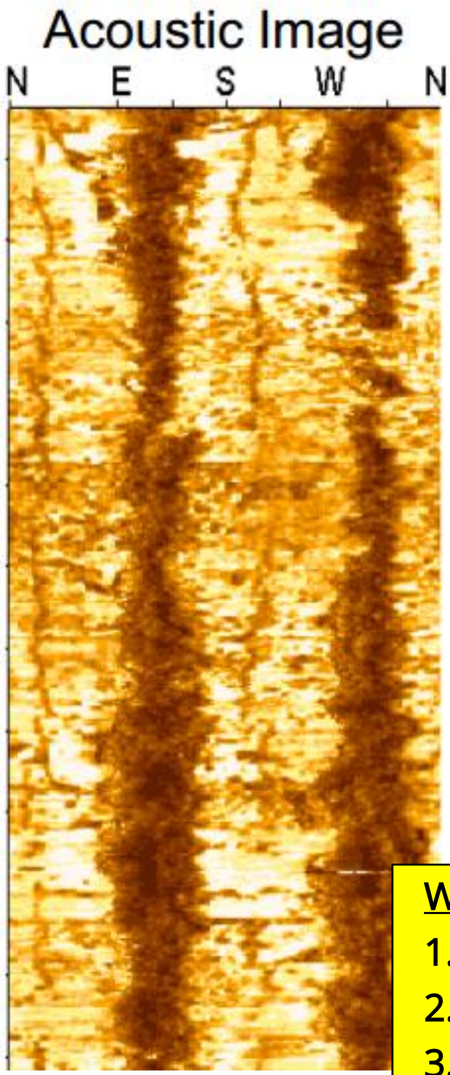
Step 5.1: Calculate σ_h (Dipole Sonic)

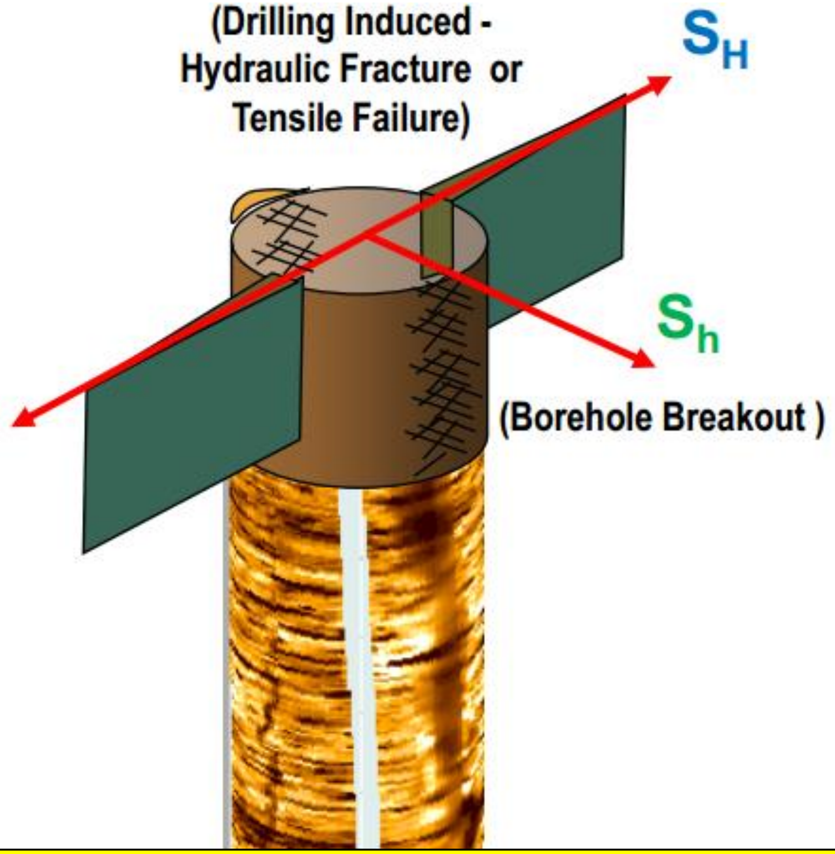
Workflow

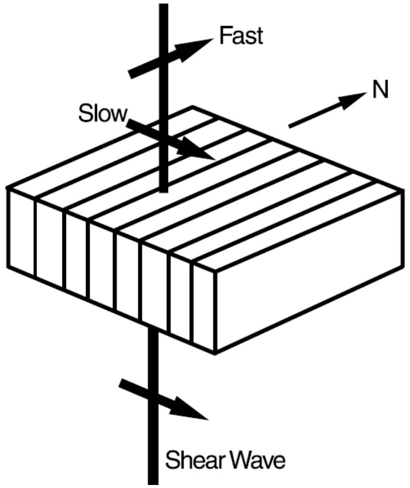
1. P_p, ν, and σ_v were calculated in previous steps
2. $\sigma_h = \nu/(1-\nu)\ \sigma_v' + P_p$
3. Calibrate using LOT or DFIT closure pressure

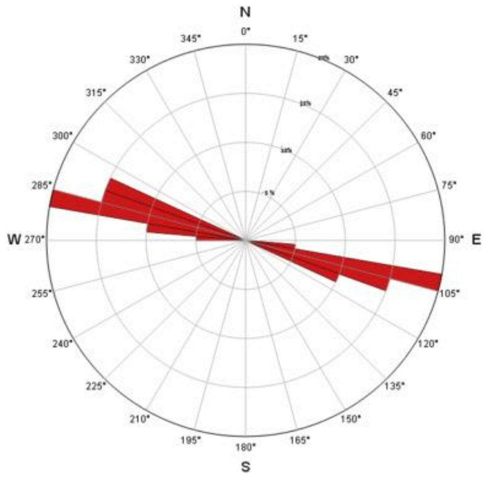


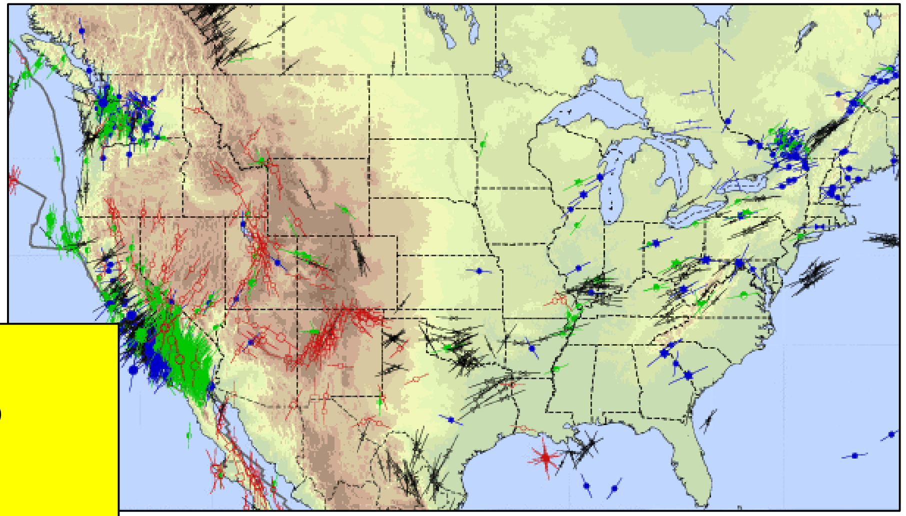
Step 5.2: Infer σ_H (Image Log, Multi-Pole Sonic)











Workflow

1. Breakout width in vertical wells indicate σ'_H/σ'_h ratio
2. Breakout points in the direction of σ_h
3. Fast-shear azimuth points in the direction of σ_H
4. www.world-stress-map.org if no images or MP Sonic

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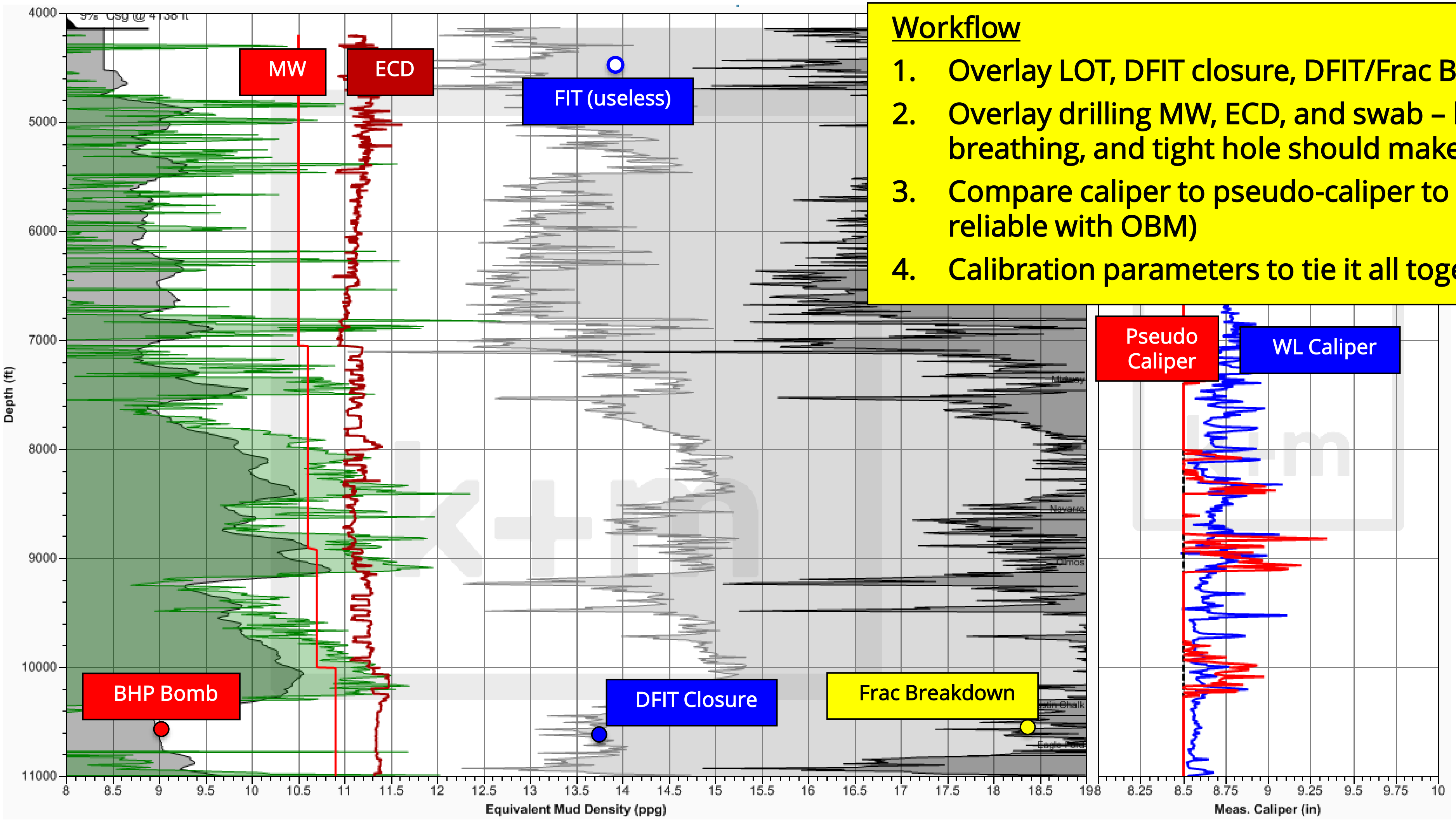
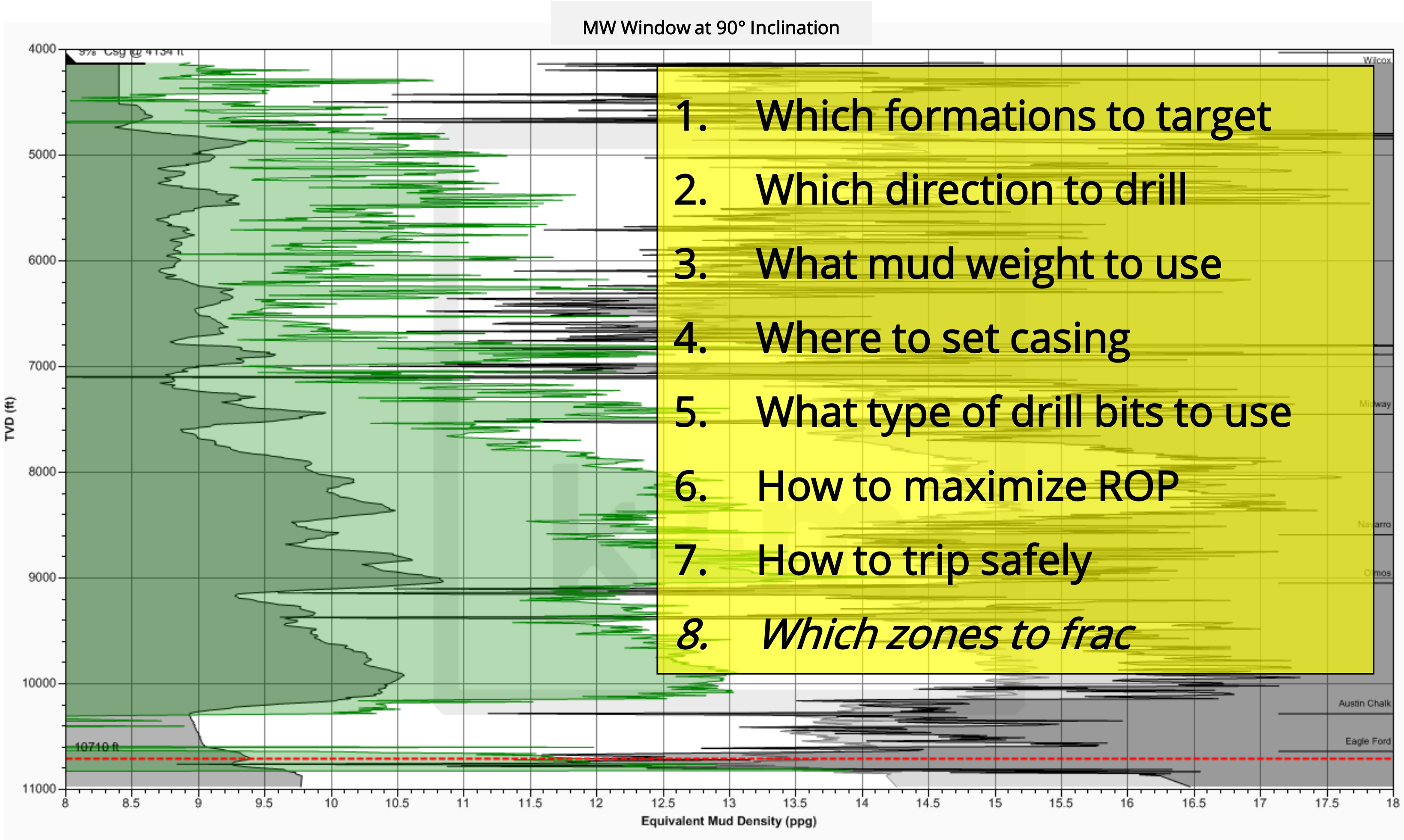
Step 6: Calibrate



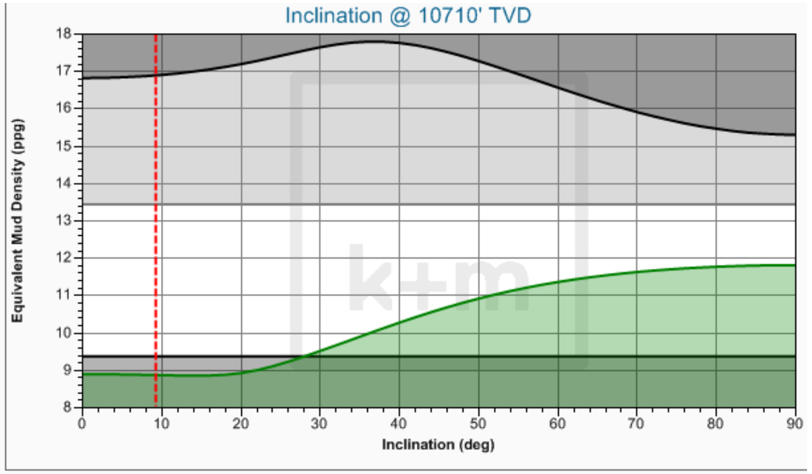
Workflow

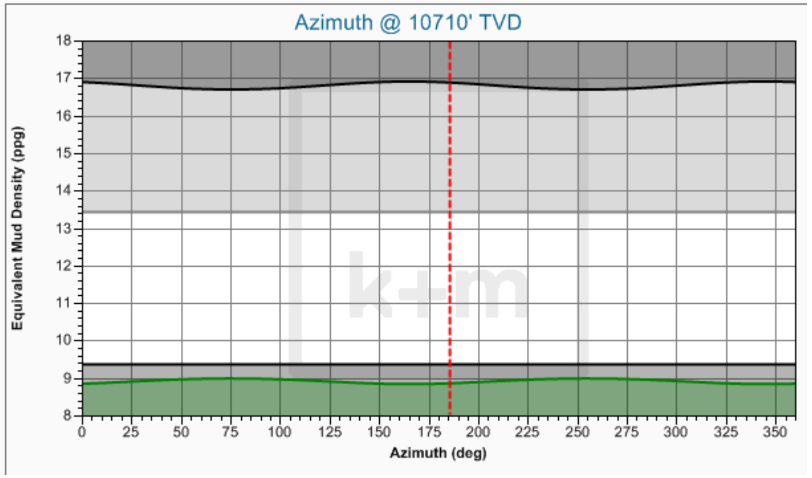
1. Overlay LOT, DFIT closure, DFIT/Frac Breakdown
2. Overlay drilling MW, ECD, and swab – kicks, losses, breathing, and tight hole should make sense
3. Compare caliper to pseudo-caliper to mimic breakout (only reliable with OBM)
4. Calibration parameters to tie it all together (UCS, σ_h, σ_H)

Output / Answers



1. Which formations to target
2. Which direction to drill
3. What mud weight to use
4. Where to set casing
5. What type of drill bits to use
6. How to maximize ROP
7. How to trip safely
8. *Which zones to frac*





In Summary

1. **Drillers:**
   - Be Spicy - Take ownership of understanding and using logs to benefit the drilling process
   - Experts can help you down the learning curve – you are not alone!
   - Geomechanics tools are commercially available! https://www.kmtechnology.com/software
2. **Non-Drillers:**
   - Start a conversation with your Drillers about the logging program and what they might need
   - Don't turn the logs off above the reservoir!
   - You can't afford to *not* run Sonic
3. **Everyone:**
   - Stop wasting money on hole problems that could have been avoided
   - Let's start talking about logs *beyond* the context of reservoir engineering and petrophysics
   - Don't let it take 20 years to learn that logs can improve drilling

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Questions?

Overburden Equation (σ_v)

$$\sigma_v = a(TVD - WD)^b + WD\rho_w g + P_a$$

Constant	Offshore GOM	Onshore US
a	0.545	0.382
b	1.0612	1.1035

Where:

- σ_v= Vertical / overburden stress, psi
- TVD= True Vertical Depth, ft
- WD= Water Depth, ft
- ρ_w= Water density, ppg
- g= Gravitational constant (0.052 on Earth)
- P_a= Atmospheric Pressure, psi (14.7)
- a=Fitting coefficient
- b=Fitting exponent

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Pore Pressure Equations (P_p)

$$V_n = V_o + A + {\sigma'_{vnorm}}^{B}$$

$$\sigma'_{vnorm} = \sigma_v - P_{hyd}$$

$$P_p = P_{hyd}\left(\frac{V_{log}}{V_n}\right)^{-e}$$

Where:

- σ_v=Overburden stress, psi
- σ'_{vnorm}=Normal effective overburden stress, psi
- P_{hyd}=Normal Hydrostatic Pressure, psi
- P_p= Pore Pressure, psi
- V_o=Velocity under zero stress, ft/sec (4600)
- V_n=Value of normal shale velocity, ft/sec
- V_{log}=Velocity from log, ft/sec
- A= Bower's coefficient (1-100)
- B= Bower's exponent (0.5-0.9)
- e= Eaton exponent (0.6 to 1.6)

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Horizontal Stress Equations (σ_h and σ_H)

$$\sigma_h = \frac{\nu}{1-\nu}\sigma_v{}'C_h + P_p$$

$$\sigma_h' = \sigma_h - P_p$$

$$\sigma_H' = \sigma_h{}'C_H$$

$$\sigma_H = \sigma_H' + P_p$$

Where:

- ν= Poisson's Ratio, unitless
- σ_v=Vertical stress, psi
- σ'_v=Effective vertical stress, psi
- σ_H=Maximum horizontal stress, psi
- σ'_H=Effective maximum horizontal stress, psi
- σ_h=Minimum horizontal stress, psi
- σ'_h=Effective minimum horizontal stress, psi
- P_p= Pore Pressure, psi
- C_h=Min Horizontal stress calibration factor (1.0-1.8)
- C_H=Max horizontal stress calibration factor (1.0-1.5)

Elastic Equations (ν and E)

$$\nu = \frac{\frac{1}{2}(\Delta t_s/\Delta t_c)^2 - 1}{(\Delta t_s/\Delta t_c)^2 - 1}$$

$$G = 1.34 \times 10^{10} \frac{\rho_b}{\Delta t_s^2}$$

$$E_{dyn} = 2G(1 + \nu)$$

$$E_{stat} = 0.032 E_{dyn}{}^{1.623}$$

Where:

- ν= Poisson's Ratio, unitless
- G= Shear Modulus, GPa
- ρ_b= Bulk Density, gm/cm^3
- E_{dyn}= Dynamic Young's Modulus, GPa
- E_{sta}=Static Young's Modulus, GPa
- Δt_c=Compressional travel time, μs/ft
- Δt_s= Shear travel time, μs/ft

Rock Strength Correlations (UCS and ϕ_f) Part 1/2

UCS correlates well with compressional travel time, Δt_c (DTCO)

$$UCS_{Sh} = 111.7\left(\frac{304.8}{\Delta t_c}\right)^{2.93}$$

Horsrud, 2001

$$UCS_{Sd} = 174000e^{(-0.036\Delta t_c)}$$

McNally, 1987

$$UCS_{Carb} = 10^{\left(2.44+\frac{109.14}{\Delta t_c}\right)}$$

Golubev, 1976

$$UCS_{Salt} = \frac{6823.8}{(\Delta t_c - 40)^{0.2912}}$$

Olea/Andrews, 2008

Where:

- Δt_c= Compressional travel time, μs/ft
- UCS_{Sh} = Shale Compressive Strength, psi
- UCS_{Sd} = Sand Compressive Strength, psi
- UCS_{Carb} = Carbonate Compressive Strength, psi
- UCS_{Salt} = Salt Compressive Strength, psi

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Rock Strength Correlations (UCS and ϕ_f) Part 2/2

Friction angle correlates with Gamma Ray

- If GR>147, ϕ_f=15
- If GR<13, ϕ_f=40
- 13<GR<147, ϕ_f=42.5-GR*0.1875

Where:

- GR= Gamma Ray, api
- ϕ_f= Friction Angle, °

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Geomechanics Engine

- *Stress Tensor Rotation – Zoback, Chapter 8*
- *Hoop Stresses around the borehole – Kirsch (or Jaeger and Cook if you don't speak German)*
- *Shear Failure Criterion – Rahimi (**Mohr Coulomb** is most common, but **Modified Lade** tends to be the most realistic / accurate)*

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References

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