T&D Implications of Using MSE in Horizontal/ERD Wells

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Outline

- MSE Refresher
  - History
  - What it tells us
- Mechanics of Torque Generation
- Implications on Horizontal / ERD Wells
- Case Study Example

MSE Refresher

- What is Mechanical Specific Energy (MSE)?
  - Measure of energy used to destroy rock
  - For a known rock strength, efficiency can be inferred

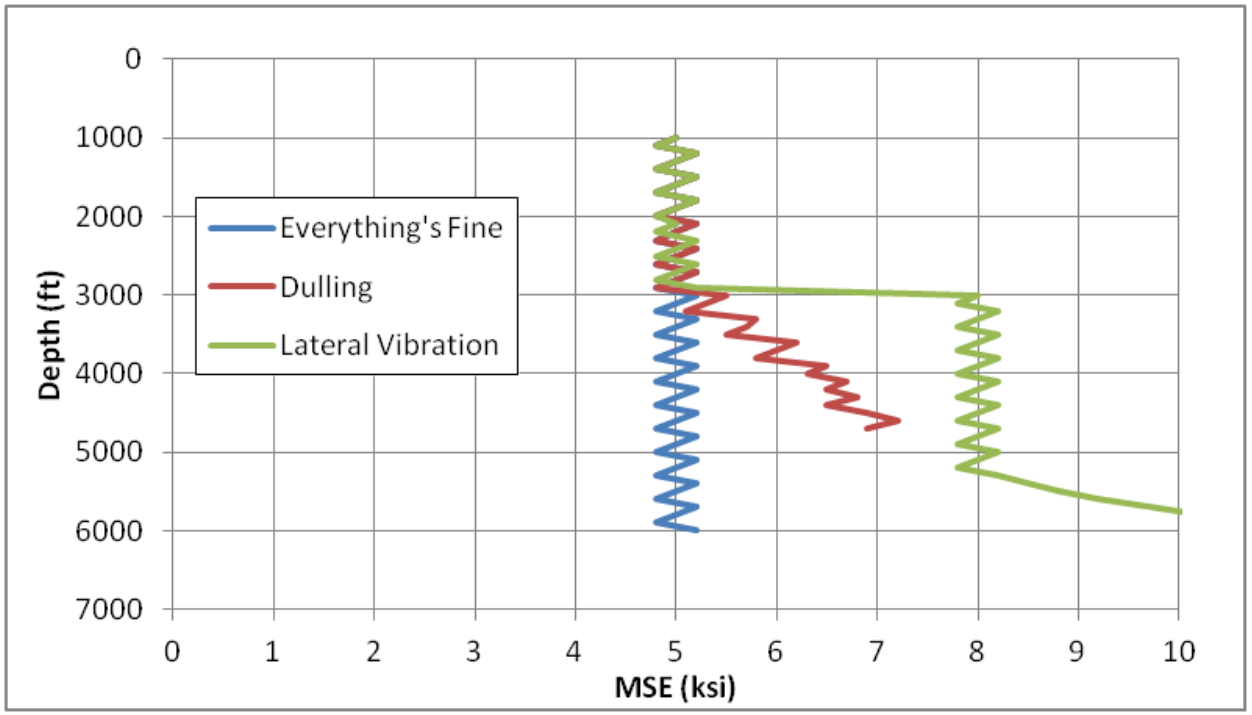
$$MSE = \frac{\mathrm{WOB}}{\mathrm{A_B}} + \frac{120 \times \pi \times \mathrm{RPM} \times \mathrm{T}}{\mathrm{A_B} \times \mathrm{ROP}}$$

- Origins?
  - Developed by Teale in 1965 (Int. J. Rock Mech. Mining Sci. Vo.2)
  - Evolved / validated by Pessier in the 1992 (SPE 24584)
  - Applied by Waughman in 2002 (SPE 74520)
  - Popularized by Dupriest in the 2005 (SPE 92194)

- Why use MSE?
  - **While Drilling:** Trends can reveal problems down hole
  - **While Planning:** Can pinpoint what is bottlenecking performance

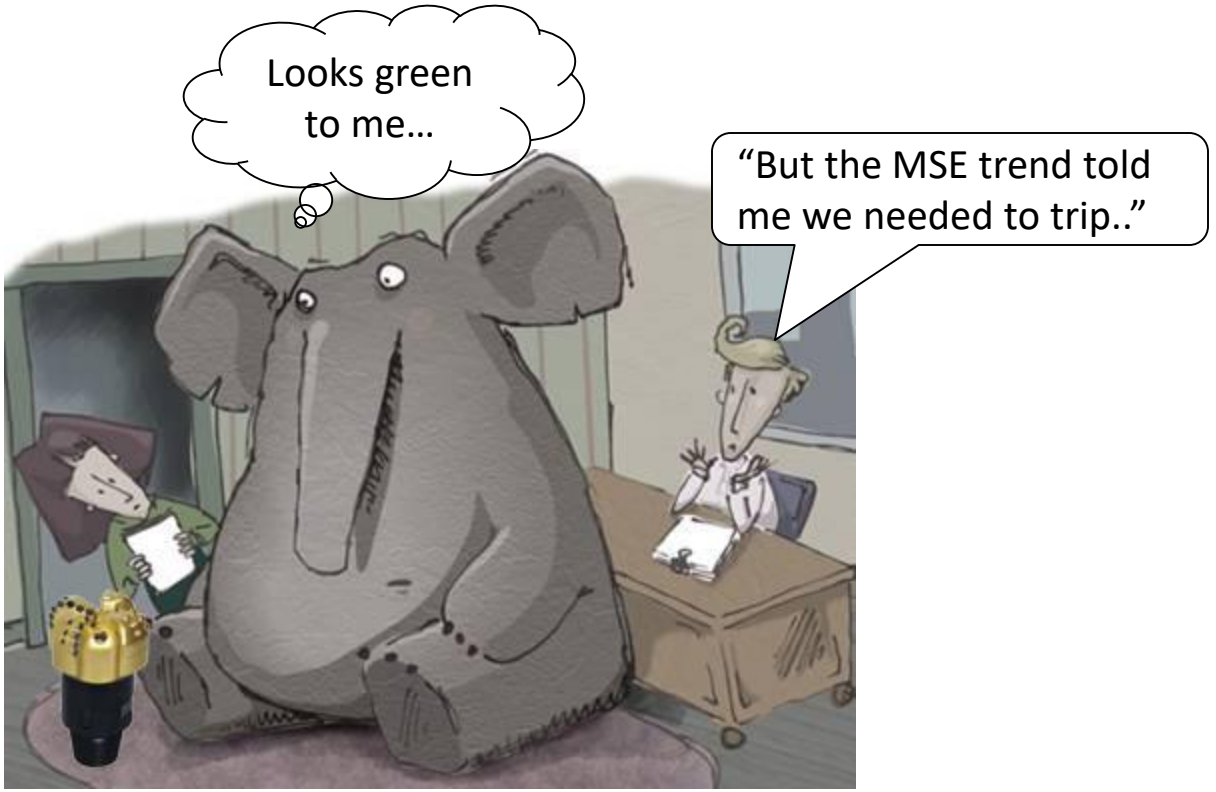
MSE Refresher

- Increasing trends may indicate a problem
  - Lateral Vibration
  - Balling
  - Bit Damage / Dulling
- Experimenting from one well to another should reveal improvements
  - Better designs should result in lower and/or more consistent MSE



Torque: The Elephant in the Room…

- Torque is the most important (and dangerous) variable in the MSE equation
  - Need to know torque at (or near) the cutting surface (bit and/or reamer)
  - We usually only measure torque at surface
  - Most surface torque is due to drill string friction
  - Simply subtracting “off-bottom” from “on-bottom” isn’t good enough



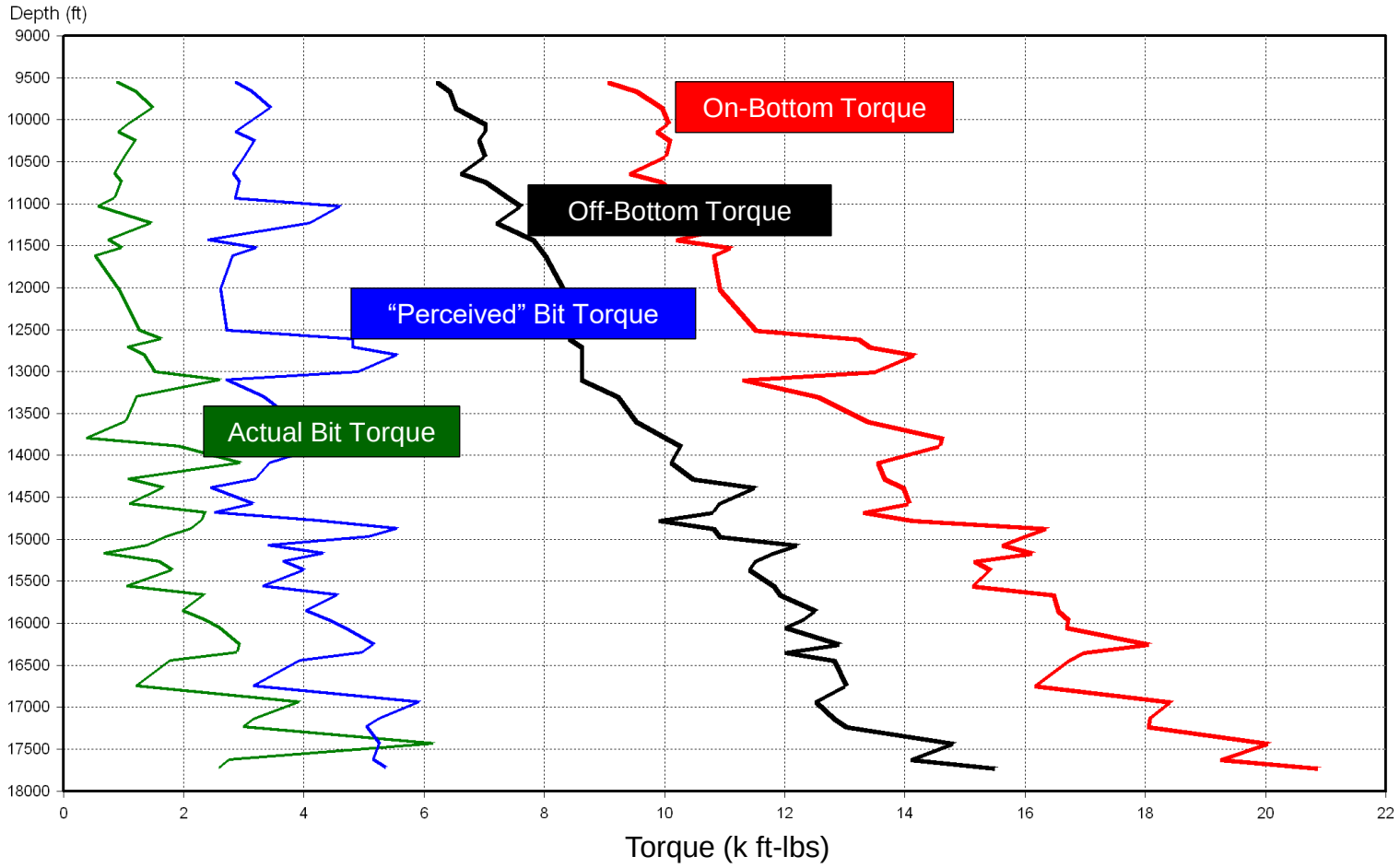
The Simple Physics of Torque

- Torque = $N \times \mu \times R_{eff}$

- Normal Force (N) can be generated in 4 ways
  1. "Low Side" – Gravity pulling pipe to the low side of the hole
  2. "Brake Drum" – Tension across a dogleg forces pipe into the side of the hole
  3. Buckling – Forces the pipe into the sides of the hole as compression increases
  4. Lateral Vibration

- Mechanisms 1-3 can be easily predicted and modeled
- Mechanism 4 can be inferred (in the absence of measurement)

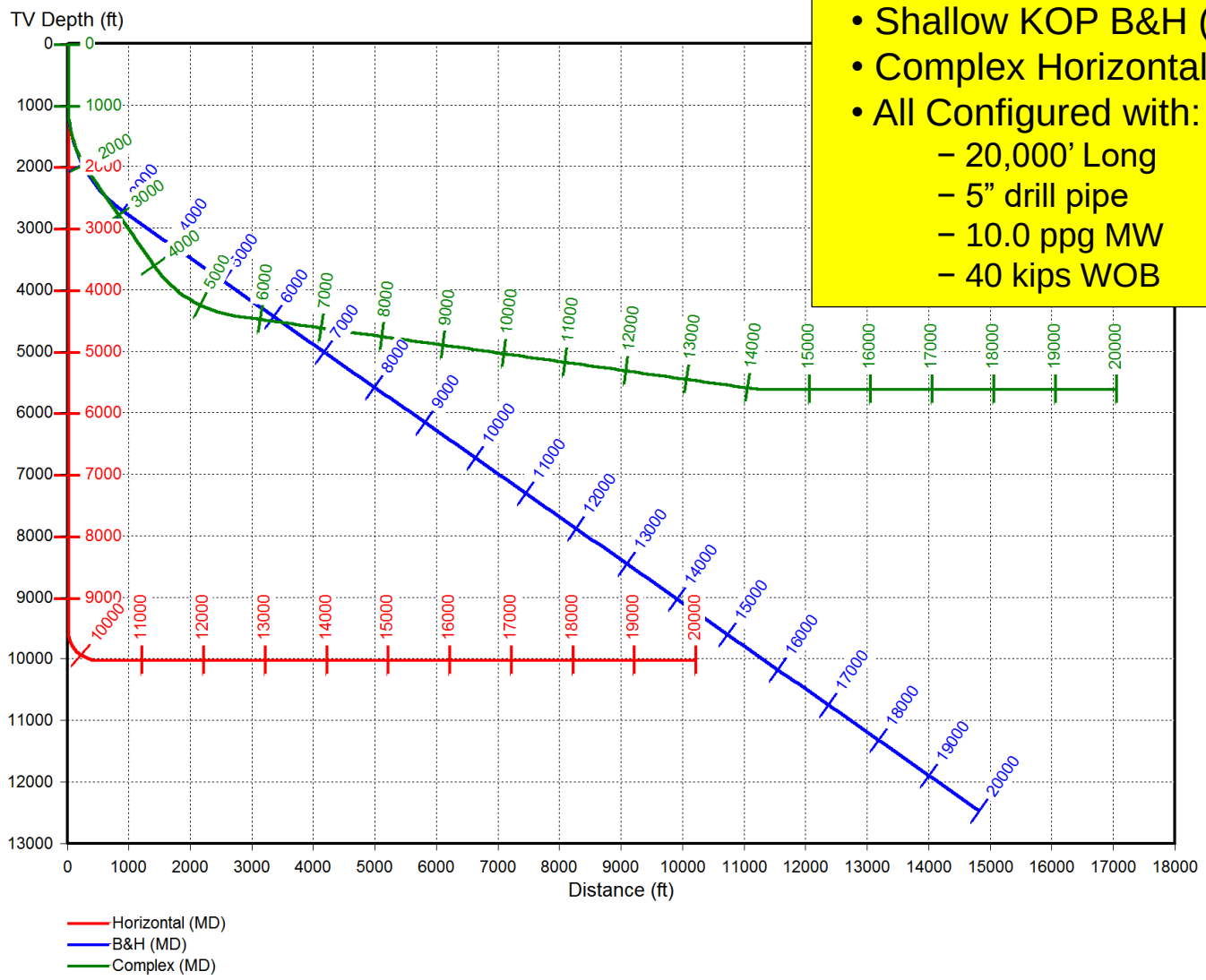
Bit Torque: Not What it Looks Like…



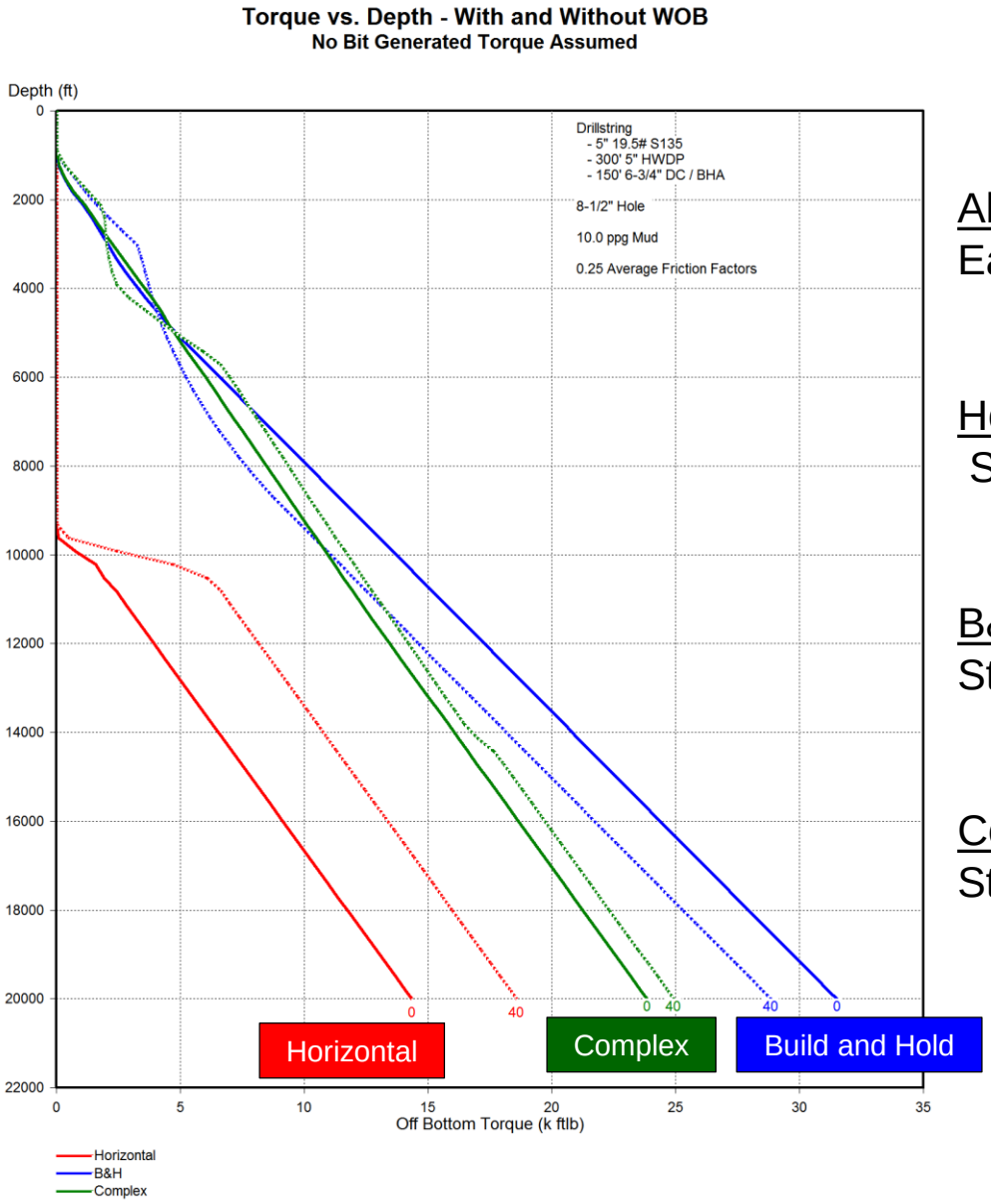
Well Path Effects

Consider These 3 Wells:

- Deep KOP Horizontal (12°/100’ BUR)
- Shallow KOP B&H (3°/100’
- Complex Horizontal (3°/100’ BUR’s)
- All Configured with:
  - 20,000’ Long
  - 5” drill pipe
  - 10.0 ppg MW
  - 40 kips WOB



Well Path Effects



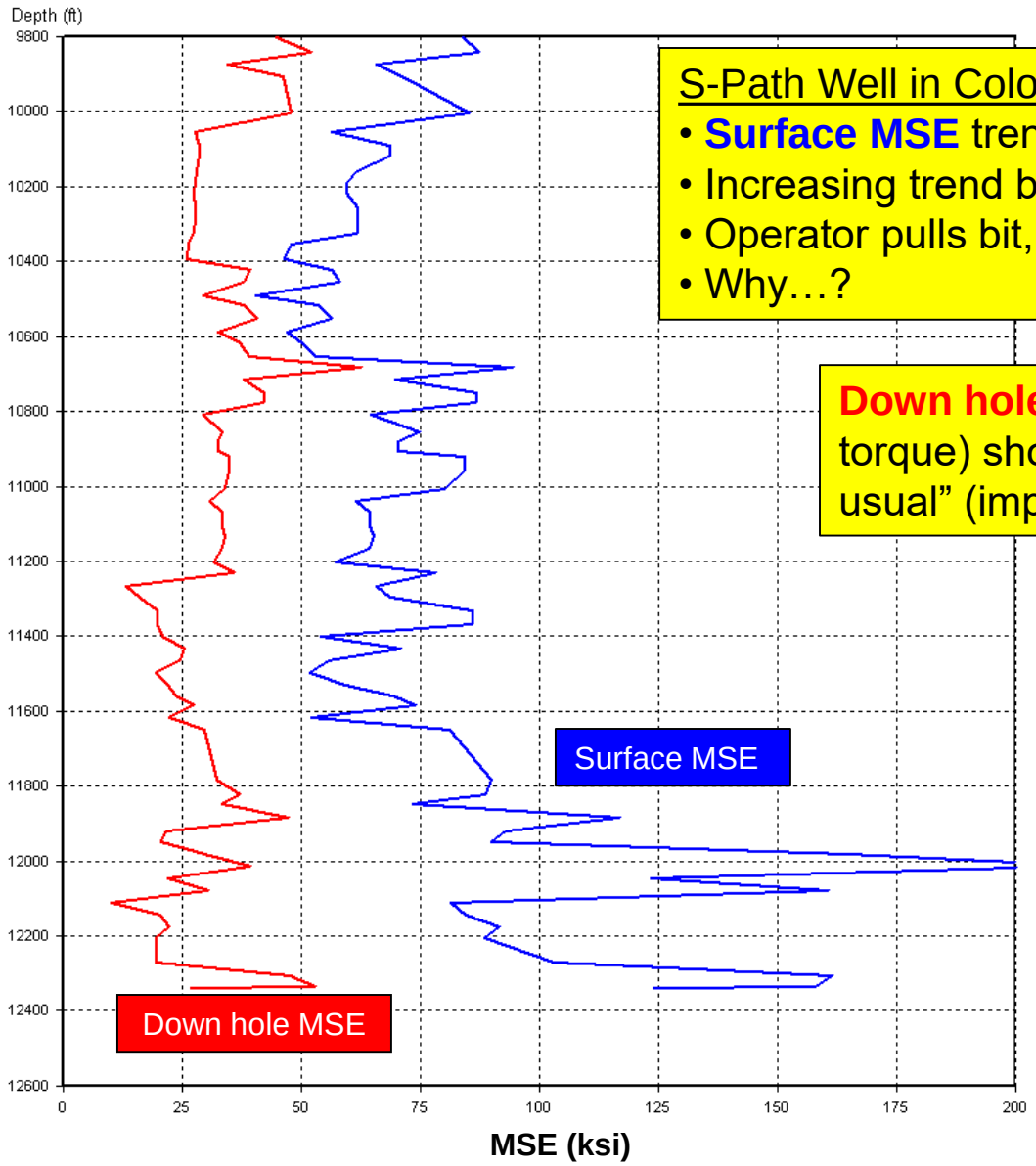
All wells with 0 WOB:
Each has a different off-bottom torque trend

Horizontal well with 40 kips WOB
String torque is 4 k ft-lbs (28%) higher

B&H well with 40 kips WOB
String torque is 3 k ft-lbs (10%) lower

Complex well with 40 kips WOB
String torque is 1 k ft-lbs (4%) higher

…Which Fouls Interpretation



S-Path Well in Colorado

- **Surface MSE** trend had been fairly constant to 11,600' MD
- Increasing trend below 11,600' suggests dulling trend
- Operator pulls bit, but is "green" at surface
- Why…?

Down hole MSE trend (accounting for string torque) shows everything was "business as usual" (improving, if anything).

Bit Torque Inference Options

Method	Pros	Cons
On Bottom Torque	Easy	Wrong. Leads to over-estimated MSE and apparent dulling trend. Can't compare MSE for wells with different trajectories
On Bottom – Off Bottom	Fairly Easy	Wrong, may lead to over *or* under estimation of MSE. Can't compare MSE for wells with different trajectories
Motor ΔP	Fairly easy.	Need a motor in the hole. Actual performance vs. handbook varies and degrades with time.
Down hole WOB/Torque	Can be accurate and close to the bit.	Measurements can drift if not frequently calibrated. By itself, can not differentiate between bit dysfunction and lower BHA dysfunction.
Calculate using T&D Engine	Accurate (if surface measurements are good). Can compare wells of different trajectories. Can reveal certain phenomenon* when combined with other methods	Complicated. Need special procedures, software, and resources.

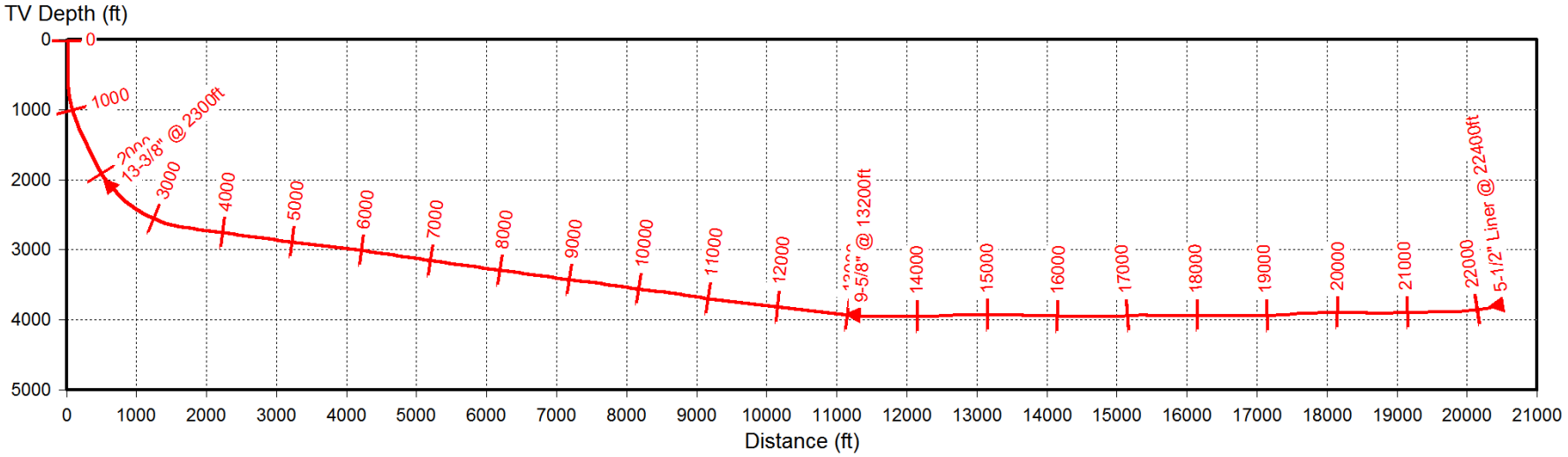
* For example, when used with DP can identify bit balling. When used with DWOB/DTOR placed below an under reamer can differentiate between bit/reamer dysfunction

How to Infer Bit Torque

1. Record off bottom torque on every stand at drilling RPM/flow
2. Back-calculate the torque friction factor
3. Recalculate the string-generated torque at every d-point using;
   - Actual surveys
   - Current WOB
   - Current TQFF
4. "Down hole" torque* is the difference between surface torque and string-generated torque

* Can verify/cross check with DWOB/DTOR sensors or motor ΔP

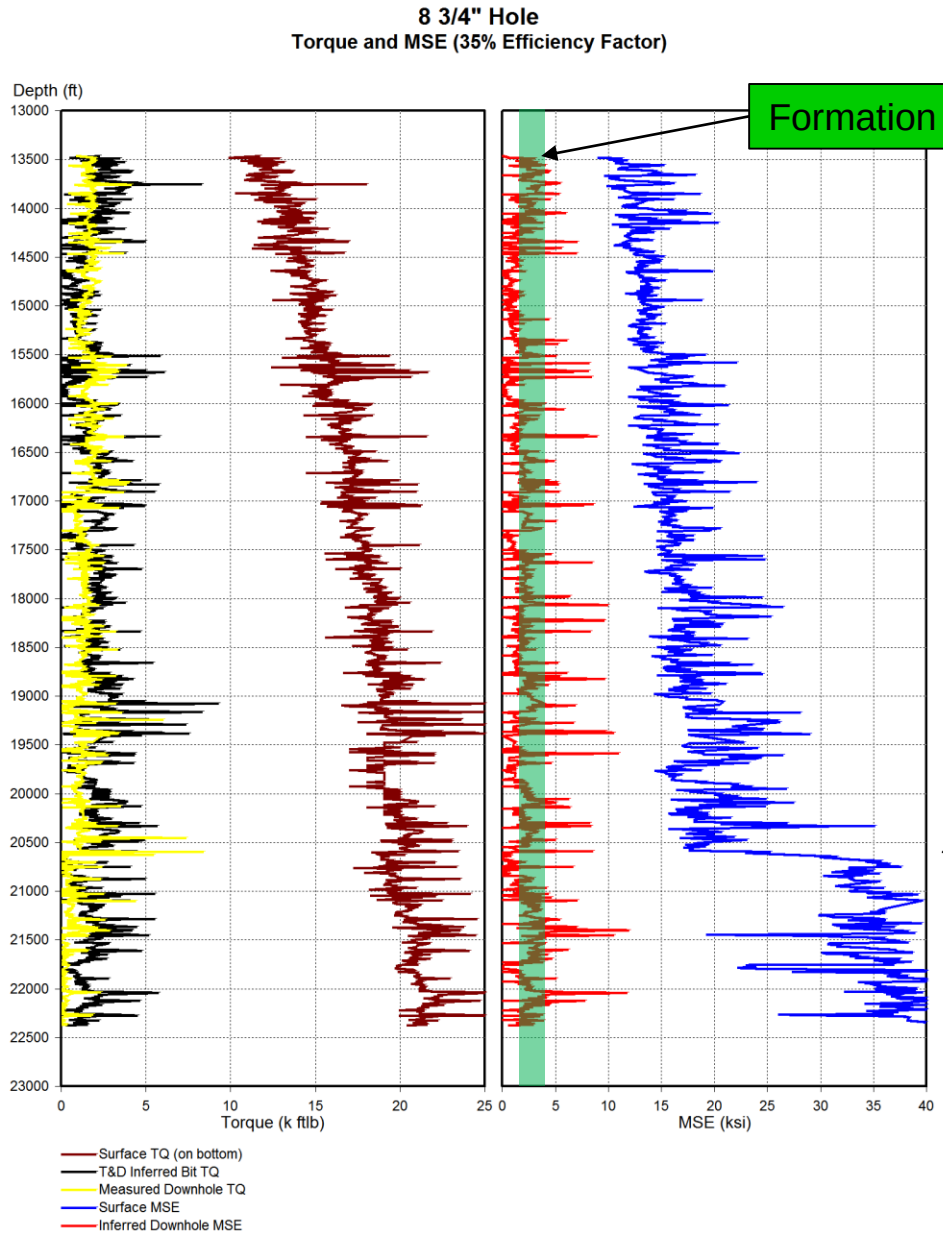
Validation: Extreme ERD Well



Consider this ER well

- Very long (>22,000’) and shallow (<4,000’)
- Tapered 5”x4½” drill string
- Highly variable WOB, Torque, RPM, ROP
- T&D engine used to normalize string generated torque and attempt to estimated bit torque

Does The Technique Work?



Formation CCS: 2-4 ksi

Conventional Interpretation:

- MSE is increasing, bit may be dulling
- Shift at 20,500' – Whirl?

"Inferred Downhole Torque" Interpretation:

- MSE and torque are fairly constant
- MSE is similar to CCS
- Everything is normal

Down hole measurements agree with calculated torque

- Reduce ROP from 300-150 ft/hr (for logging)

Summary

1. MSE is a great tool when used properly
2. Directional wells skew MSE results / interpretation
   - Must remove the string generated torque component
3. T&D modeling should be used to remove string torque
   - Doing so produces a much more accurate estimate of down hole MSE
   - The next bottleneck is surface measurement accuracy
4. Combining inferred down hole MSE from different sources can reveal interesting phenomenon