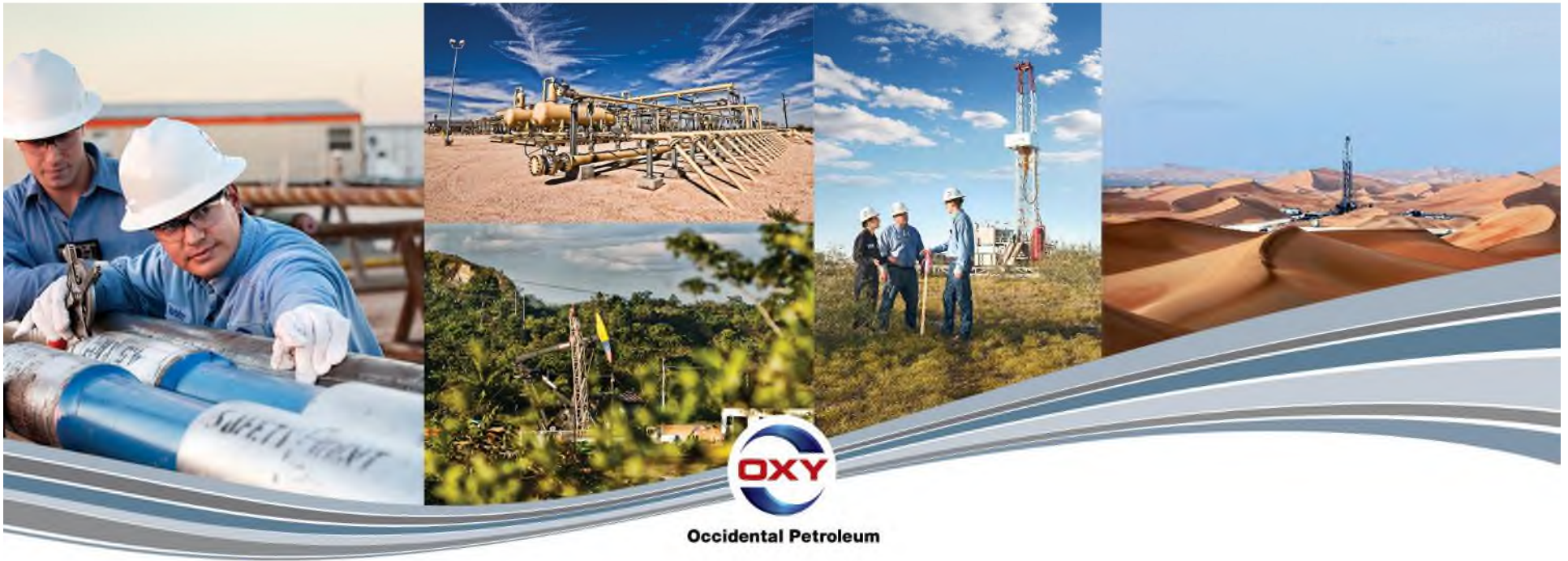


Complex Downhole Optimization in Permian Delaware Basin

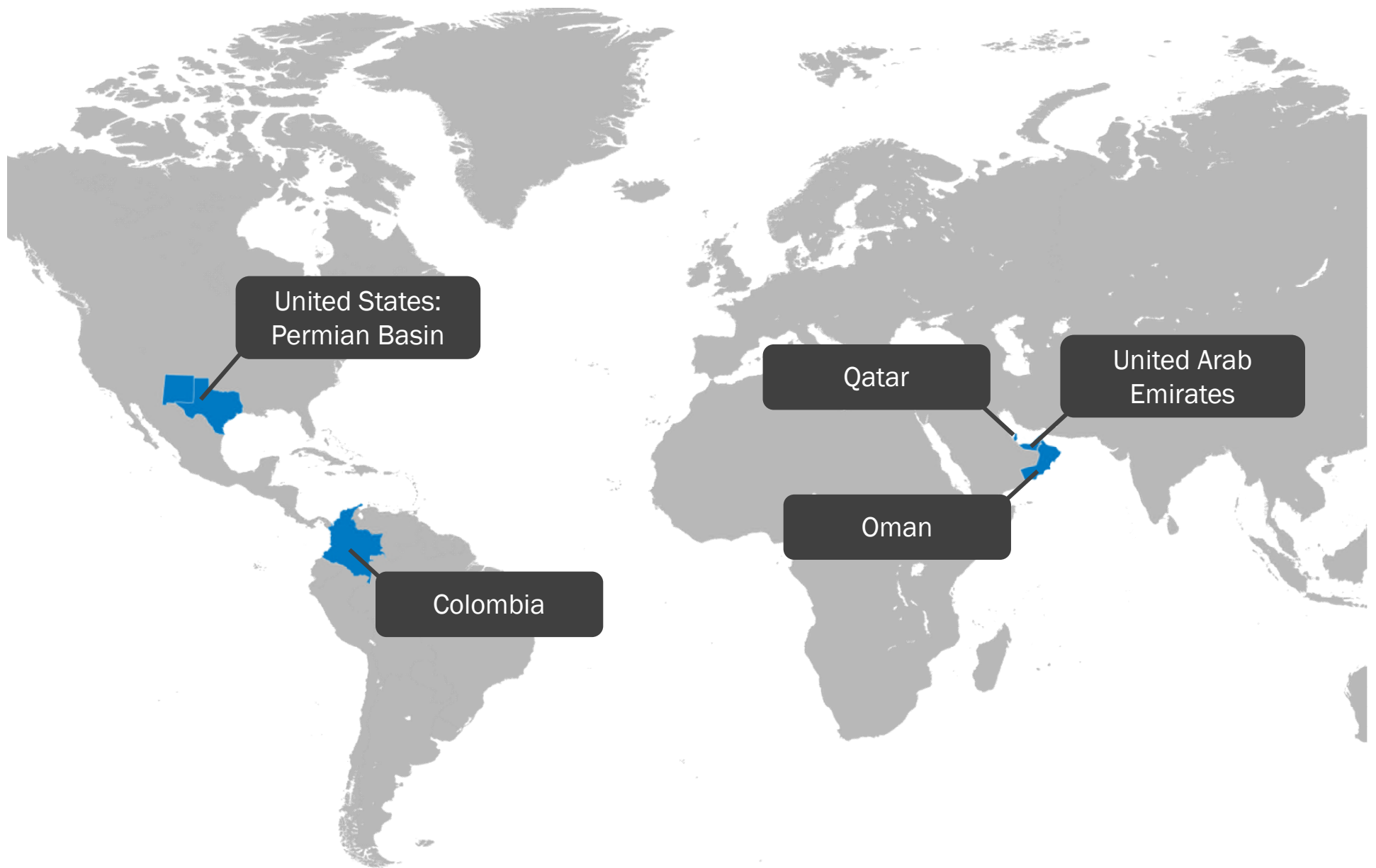
SPE Gulf Coast Section Annual Drilling Symposium

John Willis, D&C Manager, New Mexico

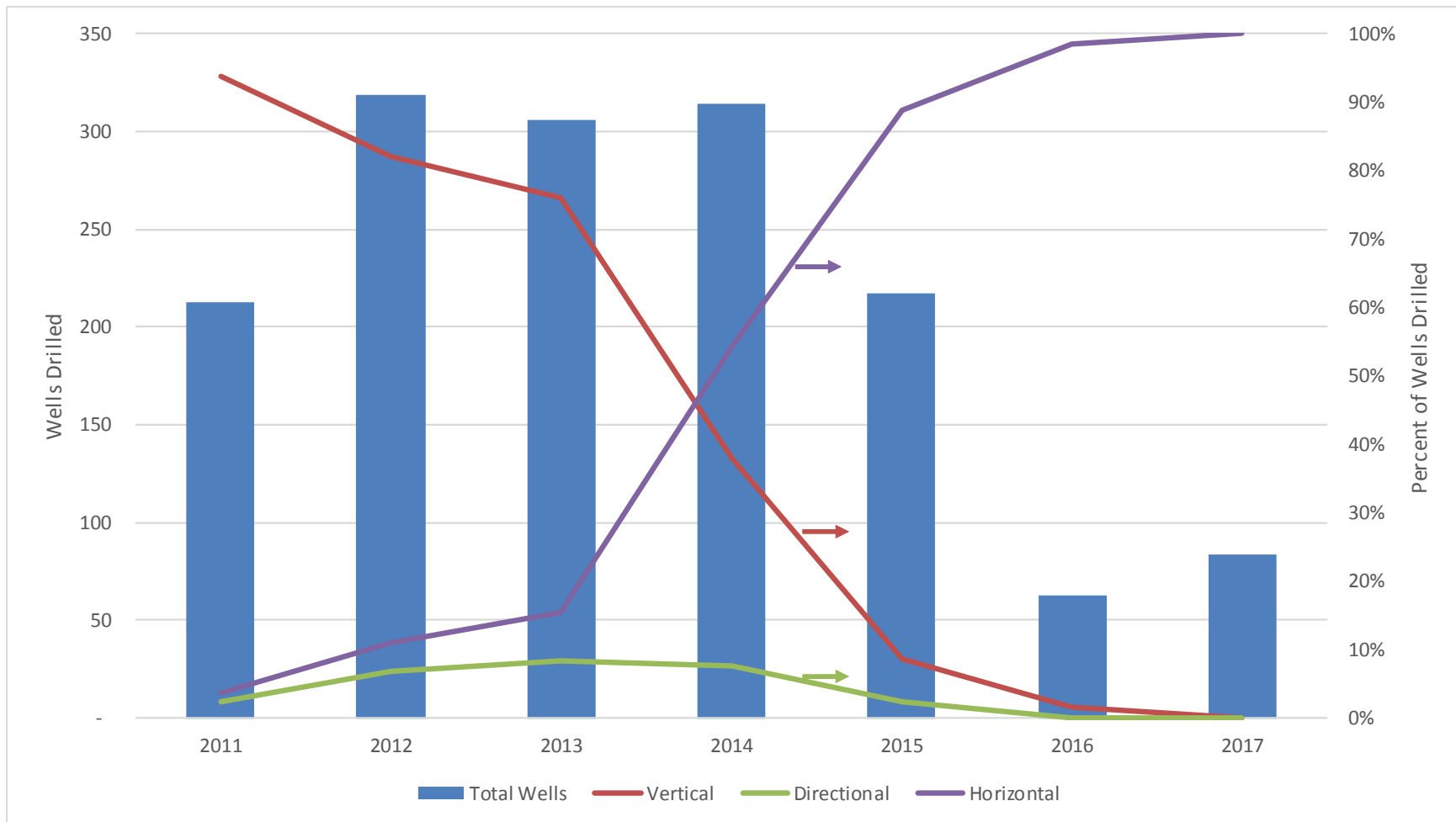
April 14, 2017



Oxy Worldwide Oil and Gas Focus Areas

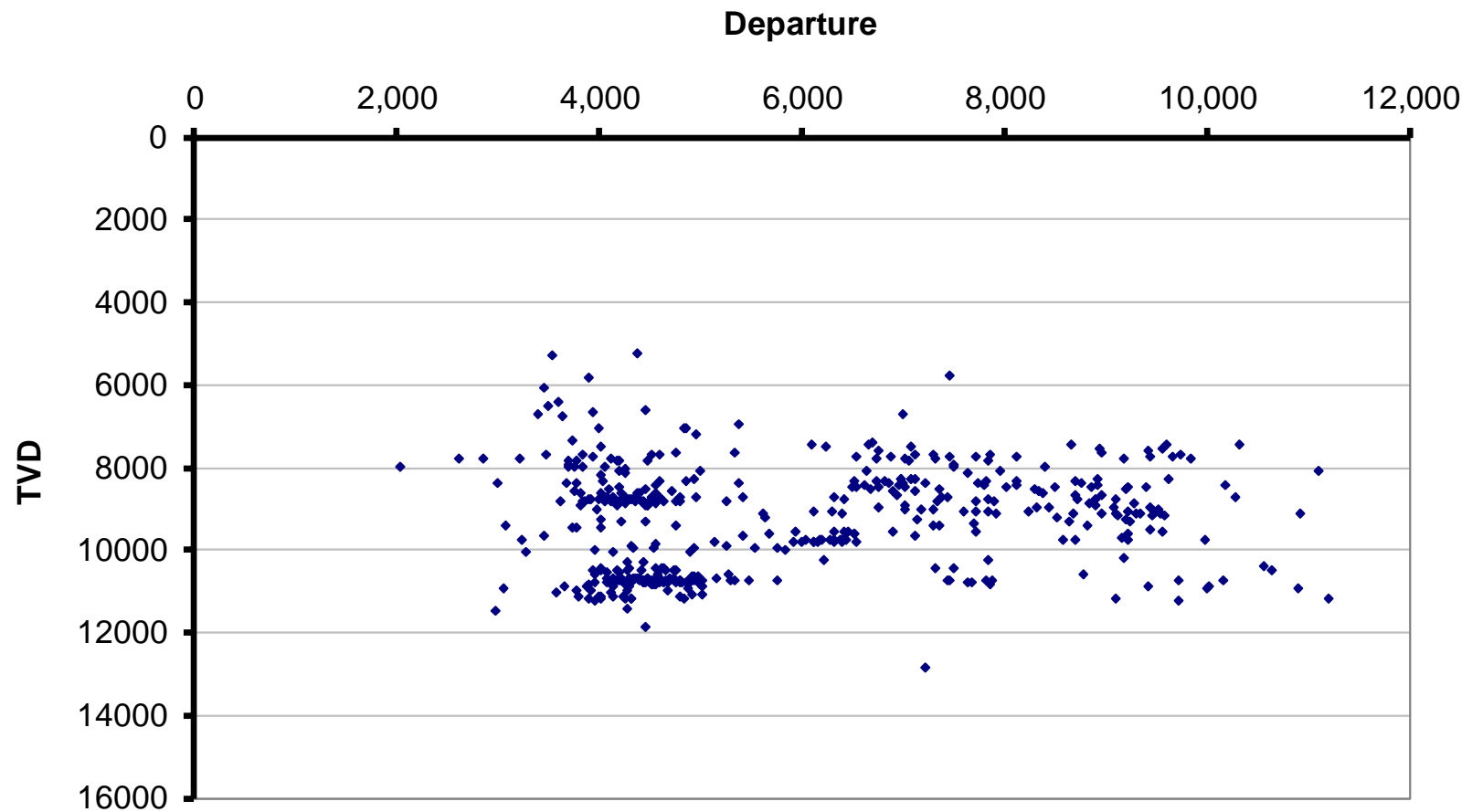


Permian Wells Mix



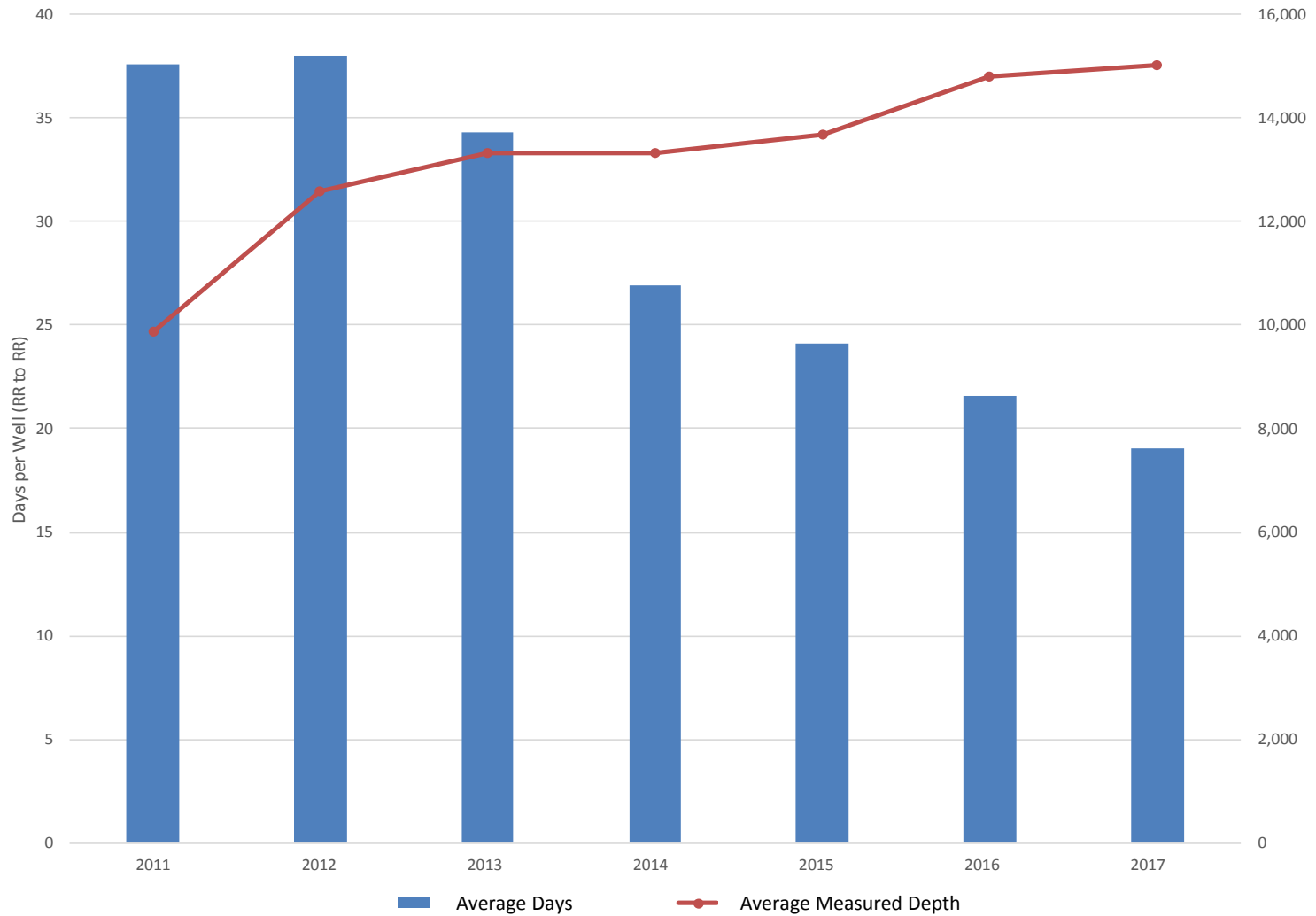
Selected wells from Oxy Permian Resources Business Units. 2017 well count estimated.

Permian Horizontal Wells



Selected wells from Oxy Permian Resources Business Units

Permian Wells Days



Selected wells from Oxy Permian Resources Business Units. 2017 performance through March.

Permian Drilling Optimization

- Reduced drilling time ~50%
- Complex – implementation and optimization
- Still room for improvement

Industry Publications on Improving ROP

SPE 102210, Dupriest, F. E., “Comprehensive Drill-Rate Management Process To Maximize Rate of Penetration”

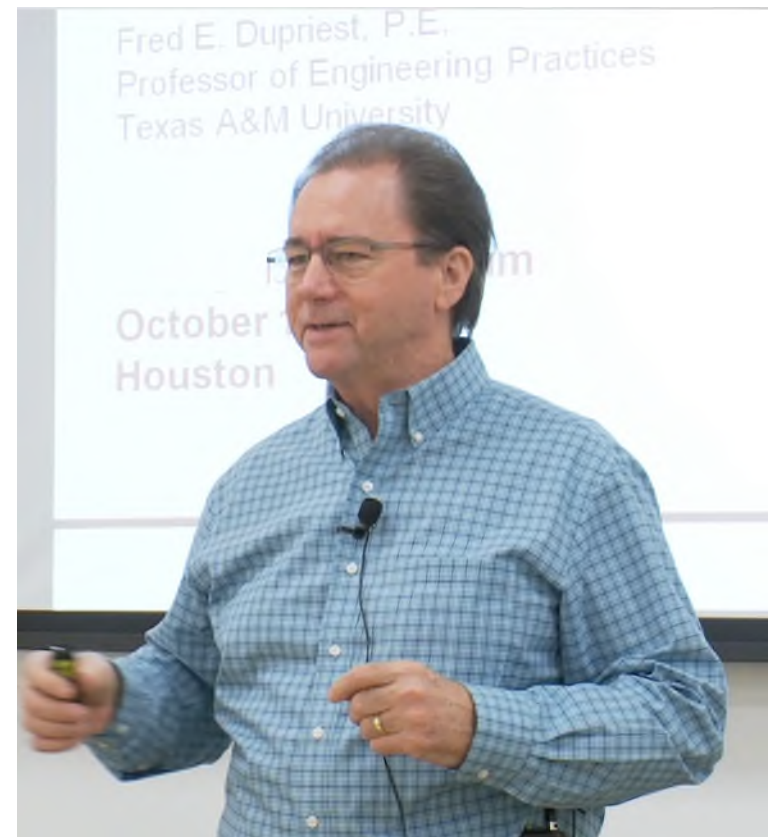
SPE/IADC 92194, Dupriest, F. and Koederitz, W., “Maximizing Drill Rates with Real-Time Surveillance of Mechanical Specific Energy”

SPE 24584, Pessier, R. C. and Fear, M. J., “Quantifying Common Drilling Problems with Mechanical Specific Energy and Bit-Specific Coefficient of Sliding Friction”

IPTC 10607, Dupriest, F. E., Witt, J. W. , and Remmert, S. M., “Maximizing ROP With Real-Time Analysis of Digital Data and MSE”

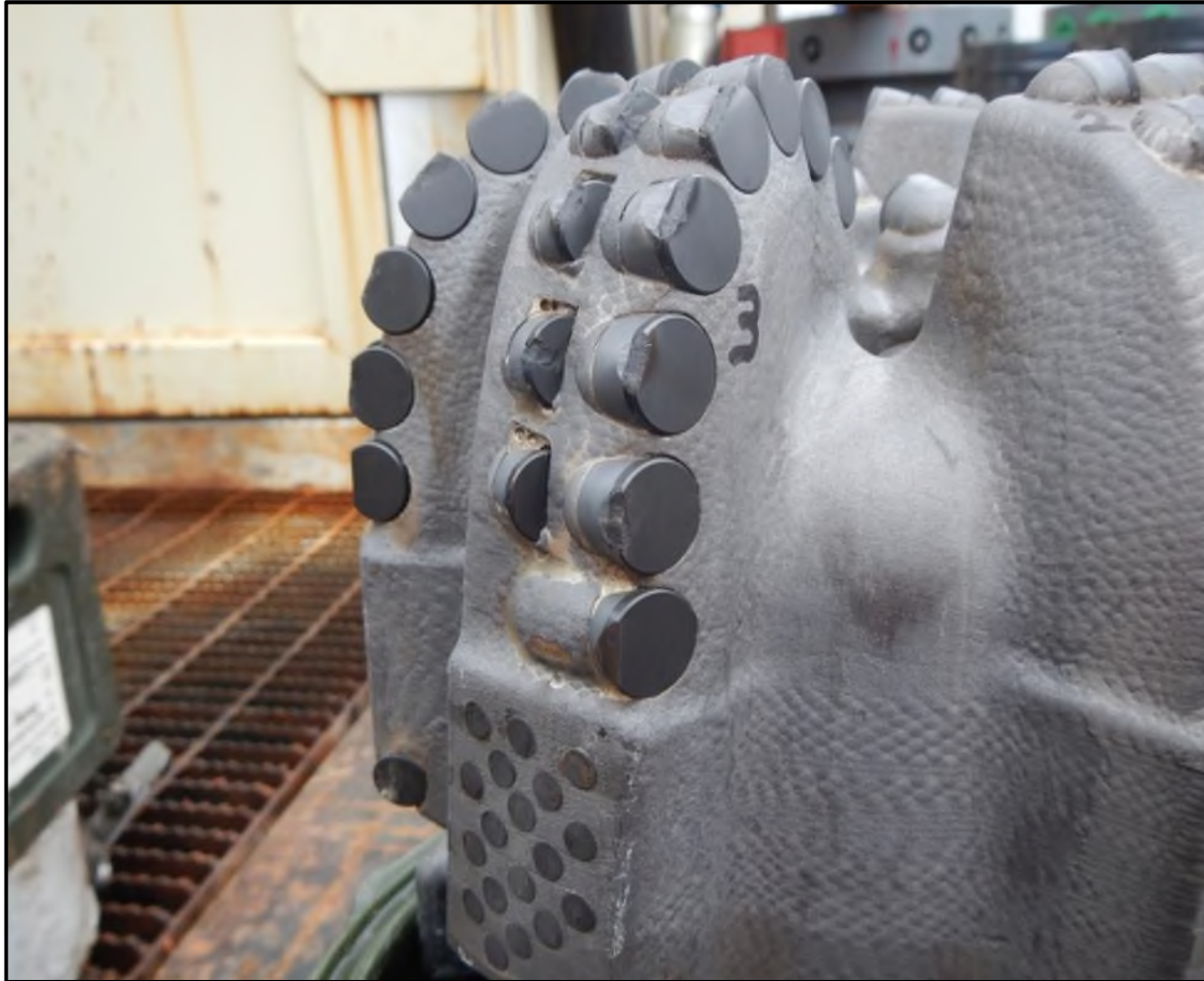
IADC/SPE 112650, Bailey, J. R. et al, “Drilling Vibrations Modeling and Field Validation”

And many others...



Fred Dupriest

Problem: Vibration Damage – Common



Solution: Run High Weight-on-Bit

High WOB is OK!

- 9-7/8" PDC
- 70 klbs WOB
- (Recommended maximum: 55 klbs)



Solution: Monitor Bit Performance with “MSE”

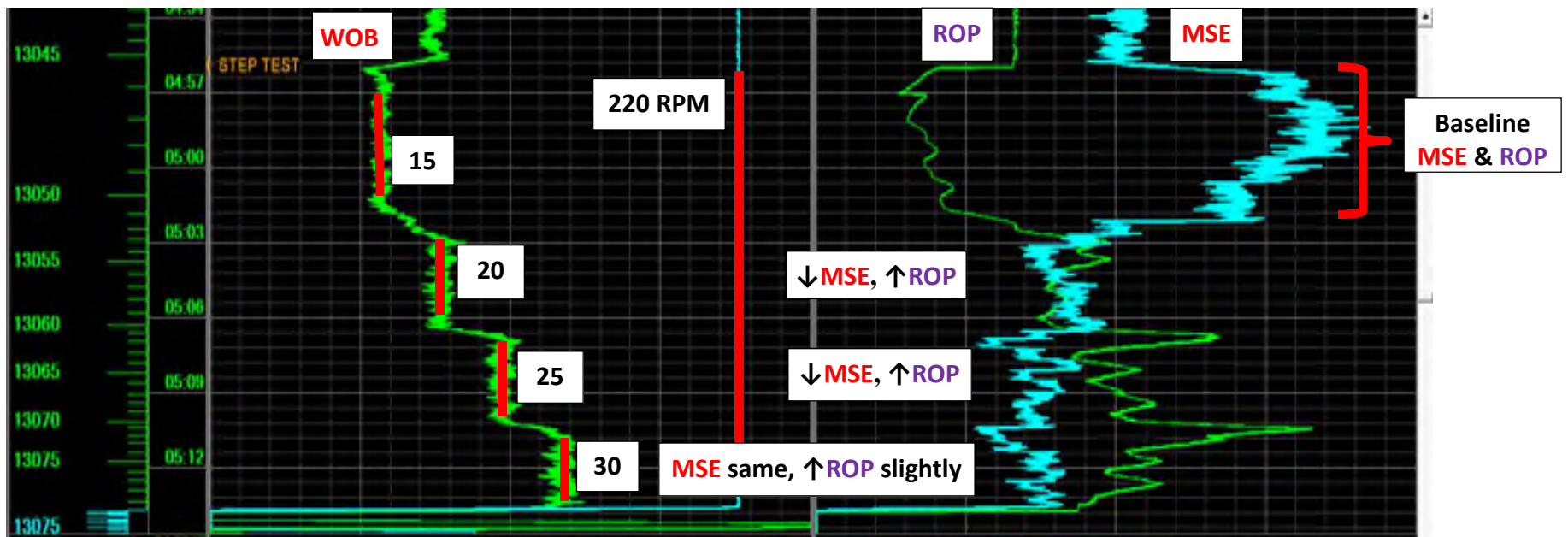
- Measures **drilling efficiency**
 - Mechanical specific energy to destroy rock (“MSE”)

$$MSE = \frac{\text{Input Energy}}{\text{Resulting ROP}} \quad (WOP, RPM, Torque)$$

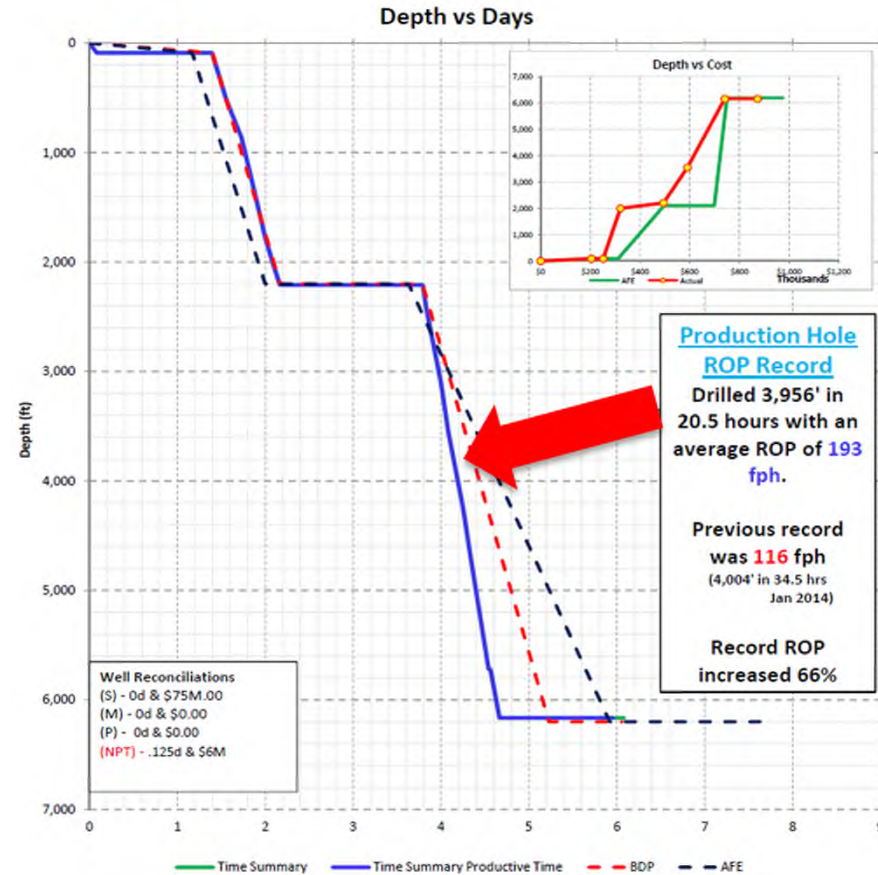
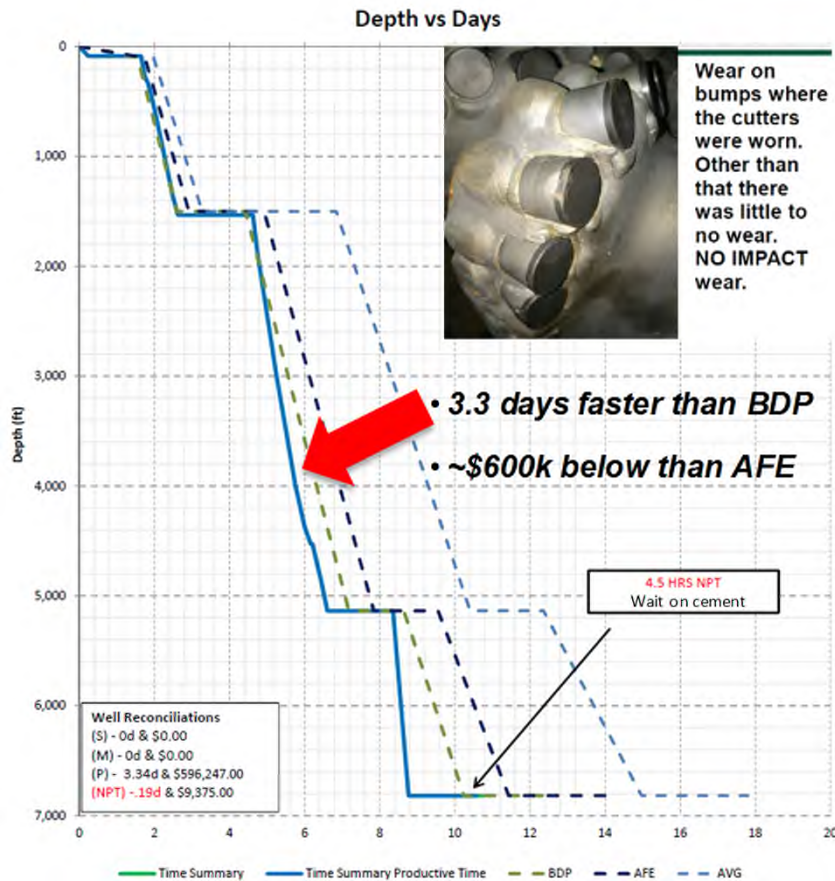
- Diagnostic tool for bit dysfunction
- Tells if the bit is more or less efficient parameters are changed

MSE Response to Change	Action
Increases	Stop, go the other way
Decreases	Do more the same way
Stays the same	Increase WOB or RPM

Solution: Find best WOB Using MSE



Results: Early Success on Simple Wells



“Mile a Day” Wells

Well	24 hr Footage
1	5,690'
2	5,293'
3	5,511'
4	5,746'

All sections 9-7/8" hole

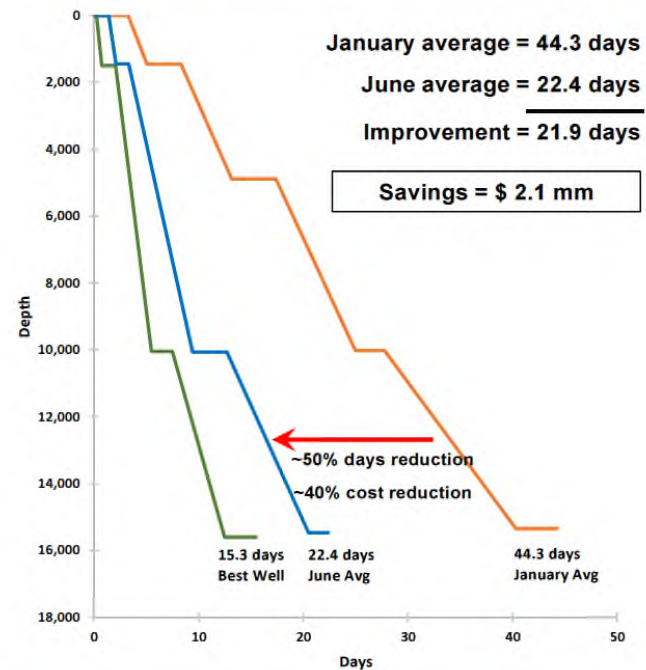


Widespread Results

Second Quarter 2015 Earnings Permian Resources – Drilling Efficiency

Delaware Basin Wolfcamp A well drilling time reduced by ~50% and costs by ~40%

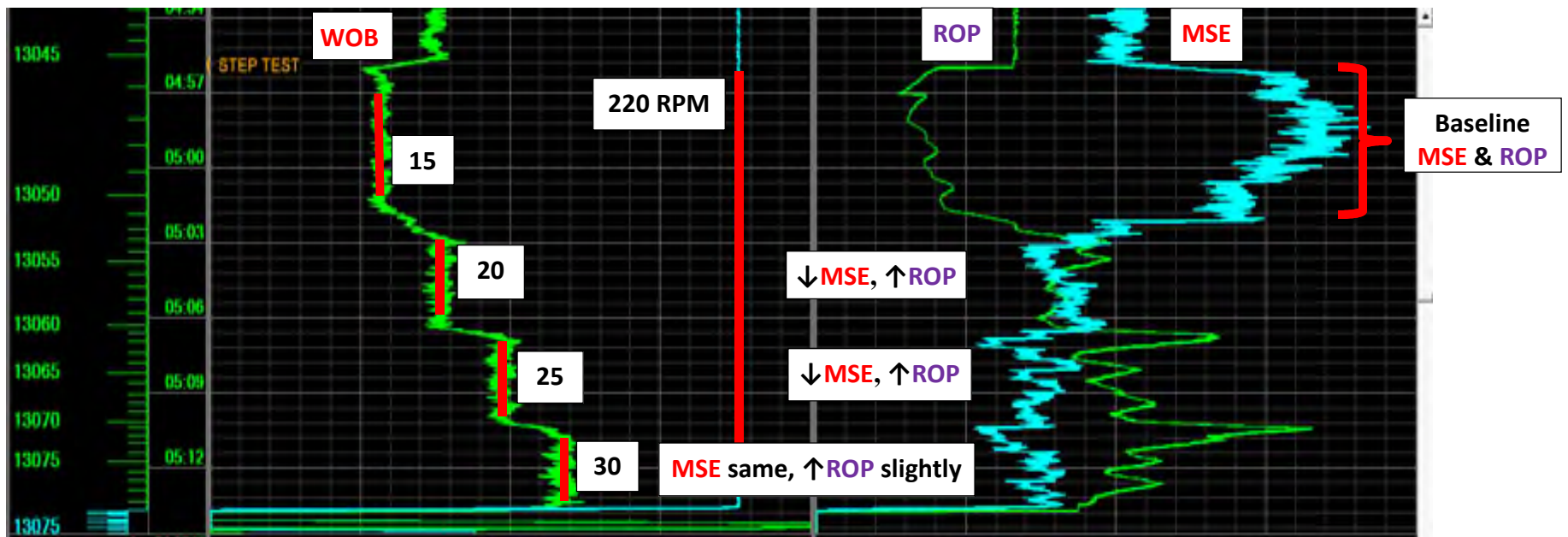
Technology	Days
Multi-well pad, reduced move time	1.8
High-resolution benchmarking	1.5
Advanced mud system to eliminate casing across salt interval	5.1
Oxy Drilling Dynamics	8.5
Curve building optimization	1.2
Vibration reduction to eliminate downhole tool failures	1.7
Rig site crew efficiency	2.1
Total Days Reduction	21.9



Some Components of Program

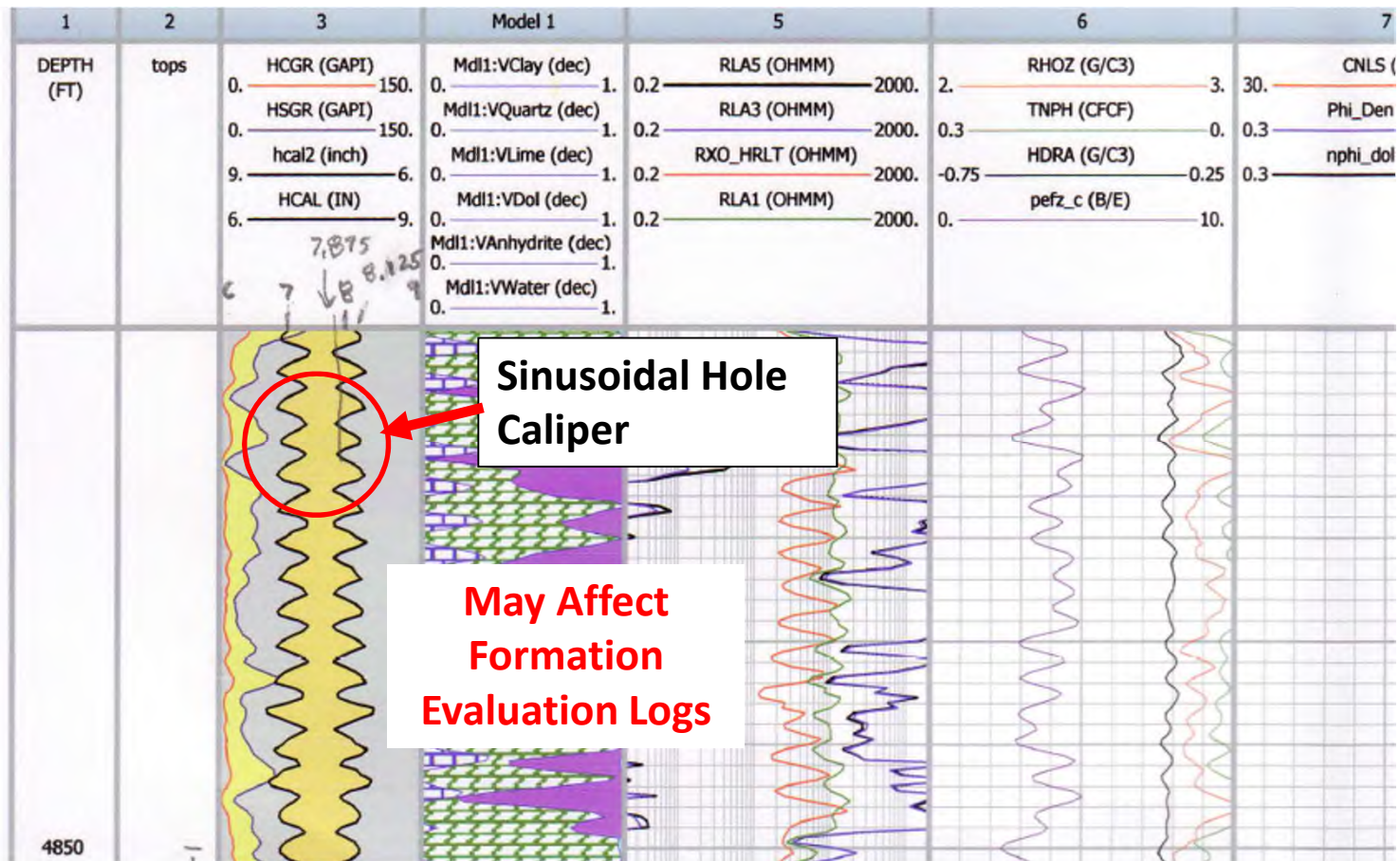
- MSE
- Bit design
- Drill String Design
 - Vibration analysis
 - Tools
- Engineering tools
 - Tool face
 - MSE comparison
 - Parameter analysis
- Engineering analyses
 - Buckling
 - BHA data sub analyses
 - Weight transfer
- New tools and systems
- Training for Drilling Engineers, Drill Site Managers, contractors
- Continuous rig site support

MSE: Monitor Bit Dysfunction



Bit Design: Long Gauge

Long gauge reduces spiraling



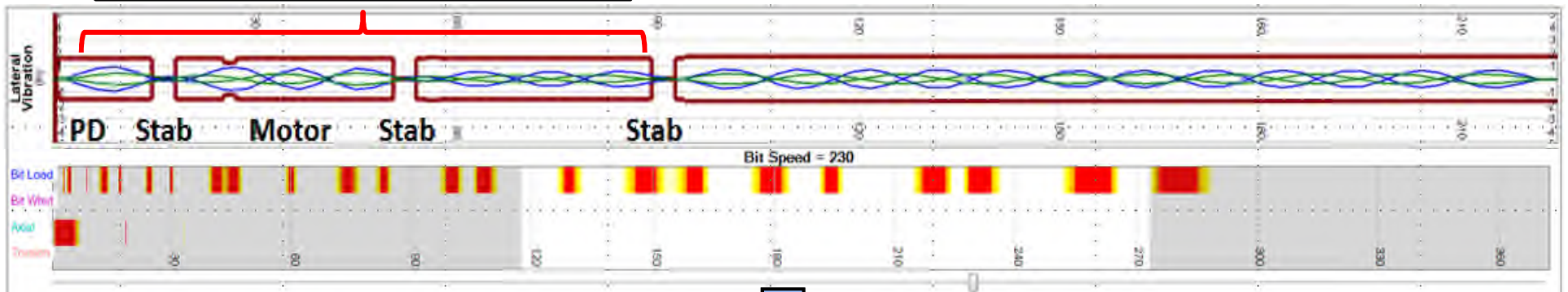
Bit Design: Depth-of-Cut Control

- Enable high WOB
- Manageable torque

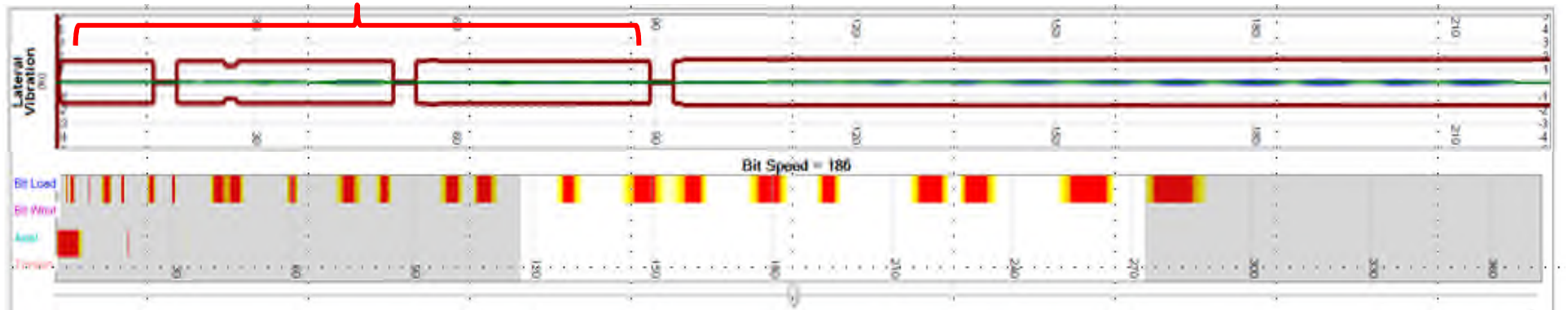


Drill String Design: Vibrations Modeling

Significant BHA Vibrations



No BHA Vibrations



Drill String Design: BHA

- Stabilizer designed to slide
- Stabilization reduces vibration and related tool failures



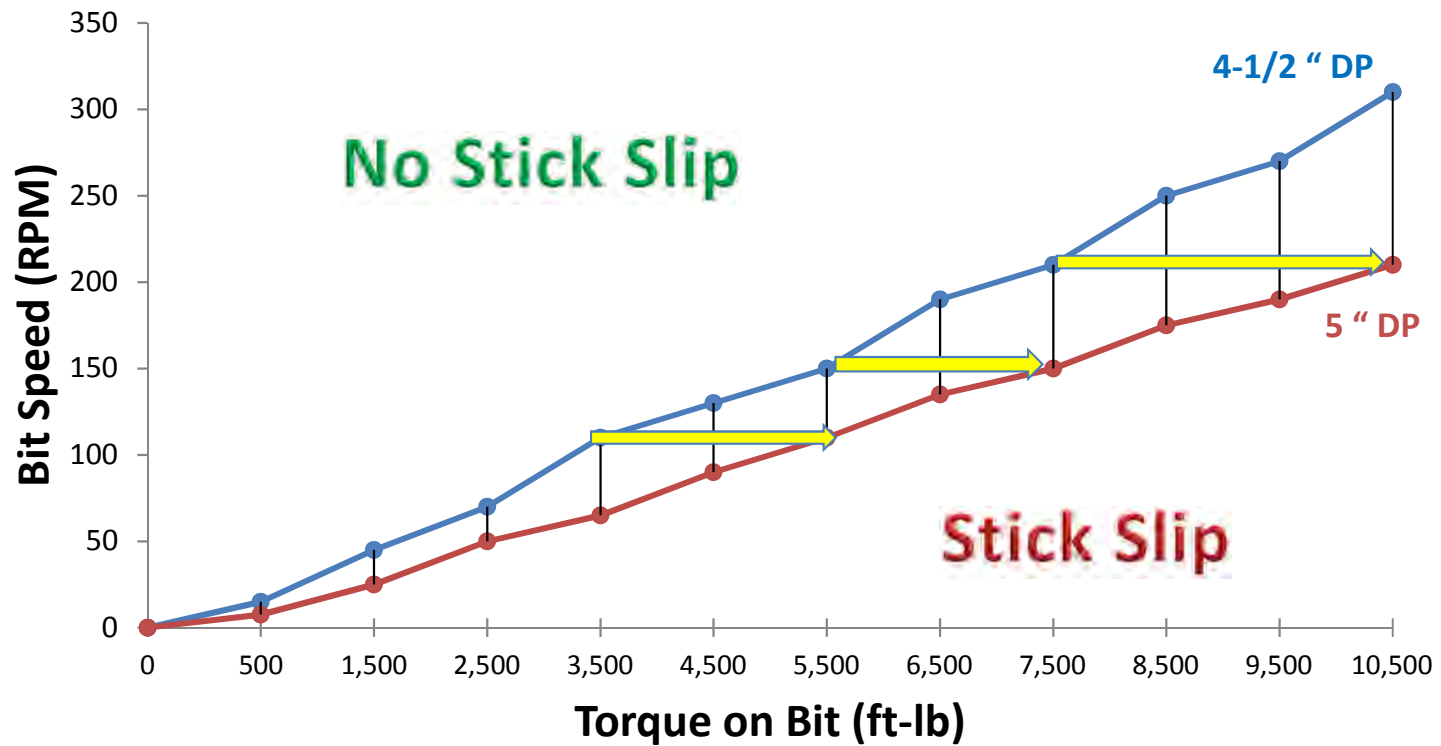
Drill String Design: Stabilization

- WOB increased 50% with stabilized BHA
- 49% fewer BHA runs
- ROP up 114%

		Time-Based %	Depth-Based %	Average ROP	Average WOB	BHAs / 9000'	Overall Average ROP
Past Motor Performance A	Sliding	25%	12%	38 ft/hr	27 klb	3.4	63 ft/hr
	Rotating	75%	88%	84 ft/hr	20 klb		
Current Motor Performance A	Sliding	14%	11%	75 ft/hr	42 klb	1.72	182 ft/hr
	Rotating	86%	89%	204 ft/hr	31 klb		
Past Motor Performance B	Sliding	22%	9%	32 ft/hr	25 klb	2.48	110 ft/hr
	Rotating	78%	91%	120 ft/hr	25 klb		
Current Motor Performance B	Sliding	25%	11%	66 ft/hr	43 klb	1.28	188 ft/hr
	Rotating	75%	89%	209 ft/hr	35 klb		

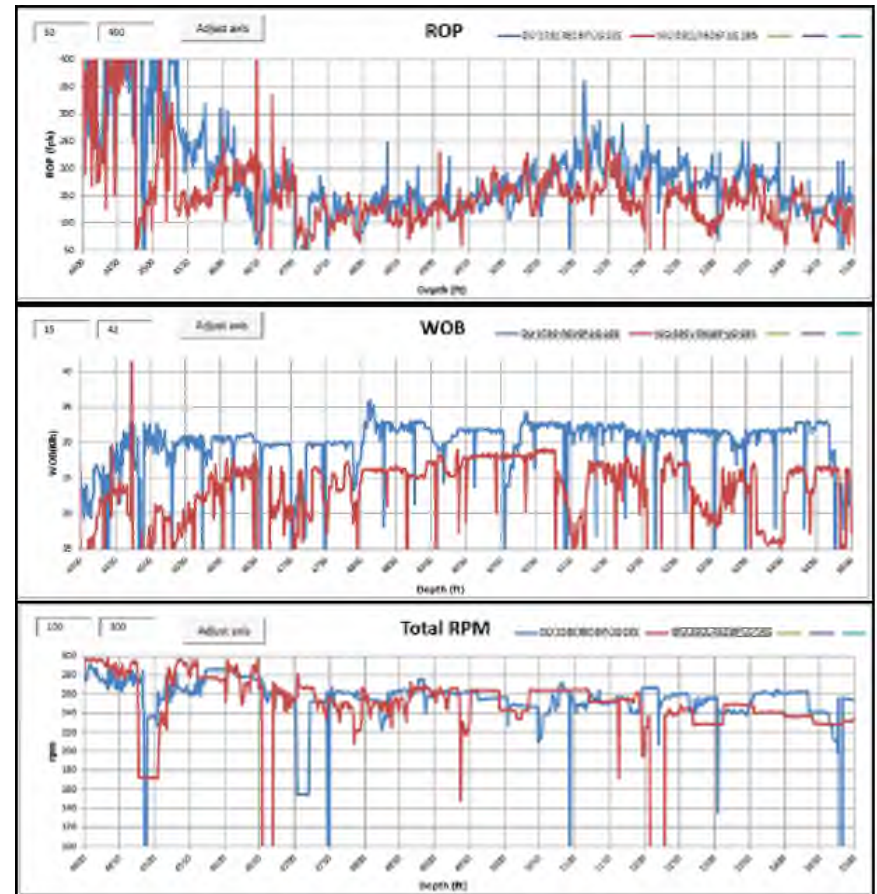
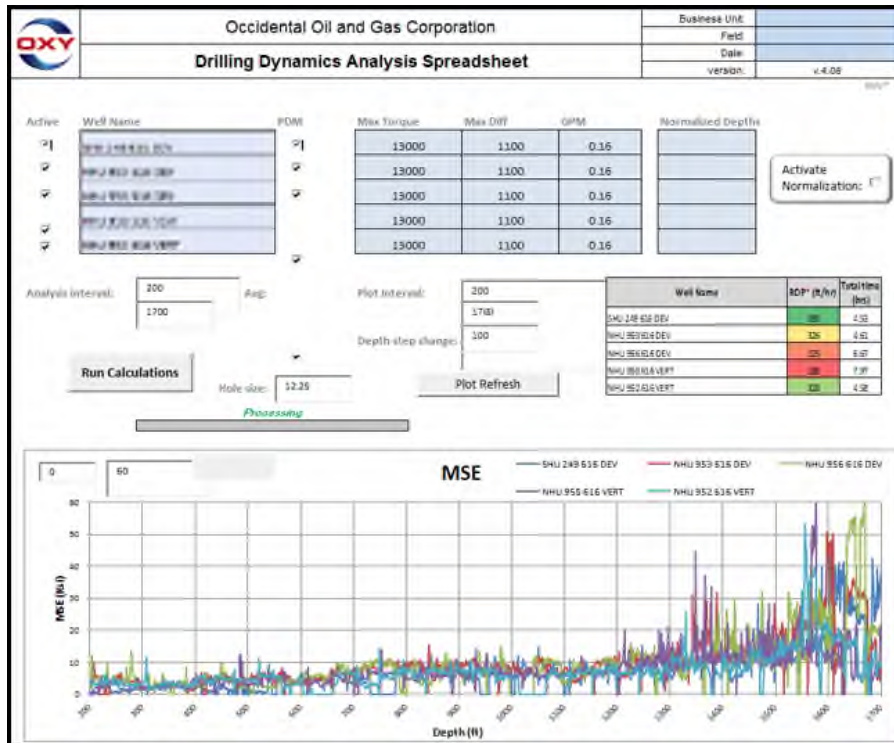
Drill String Design: Bigger Drill Pipe

Stick-Slip Region at 4,000 ft

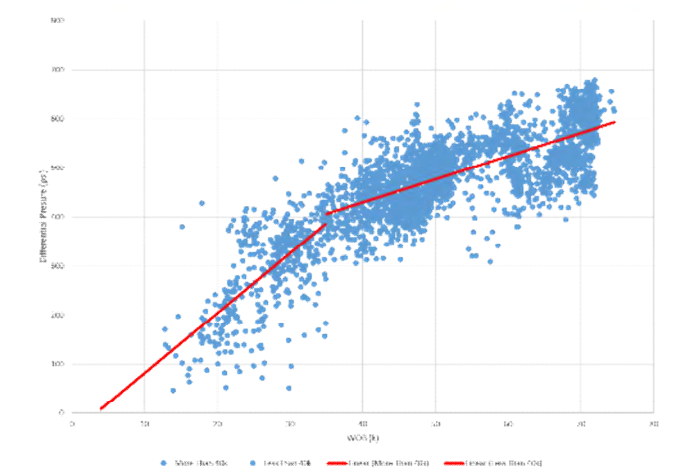
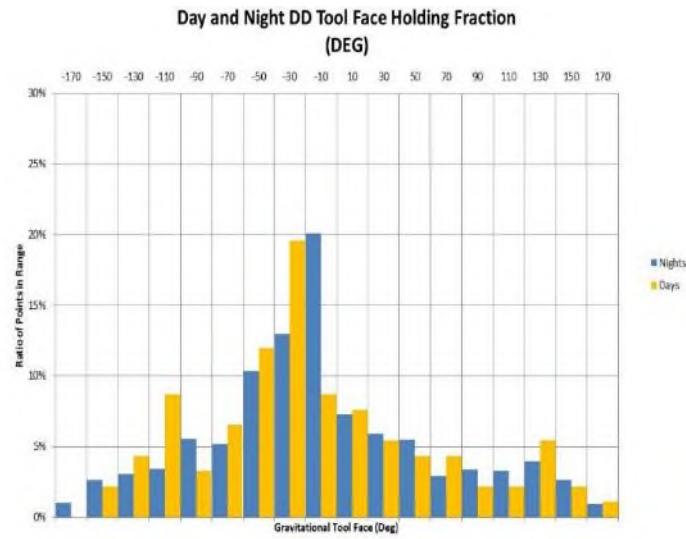
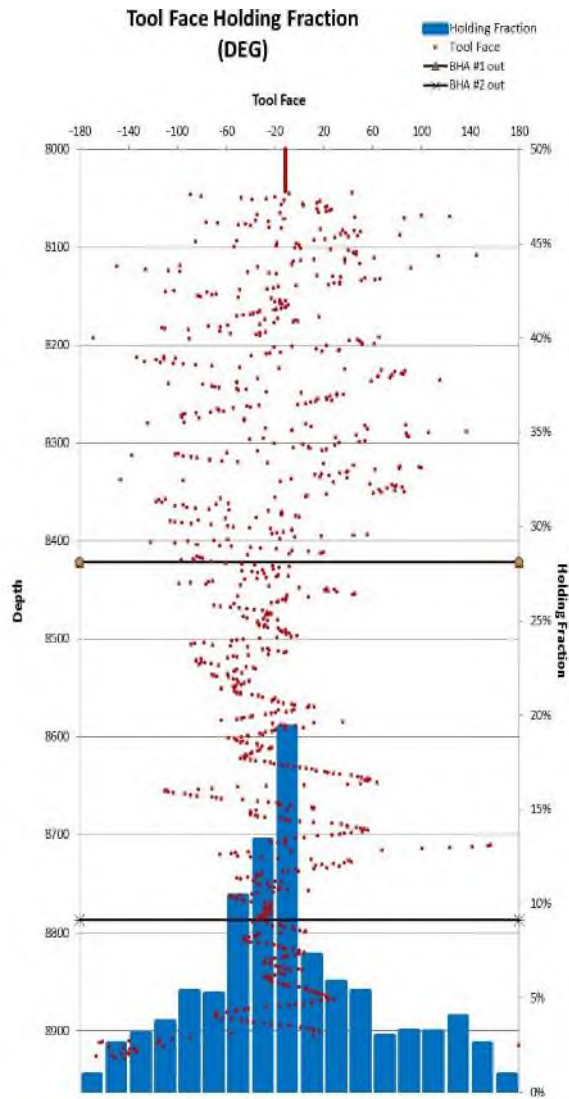


Engineering Tools

- In-depth high-res data analysis



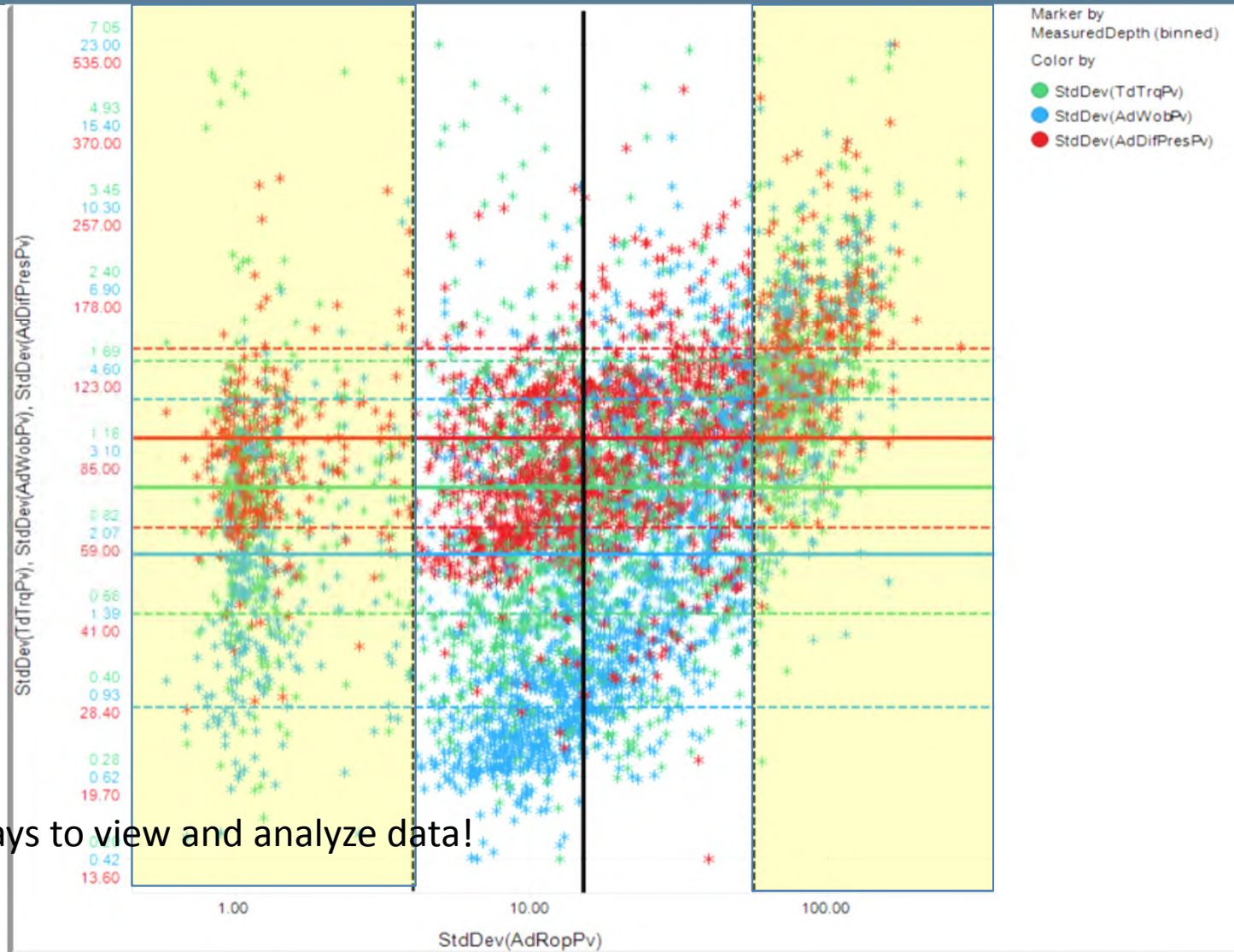
Engineering Tools



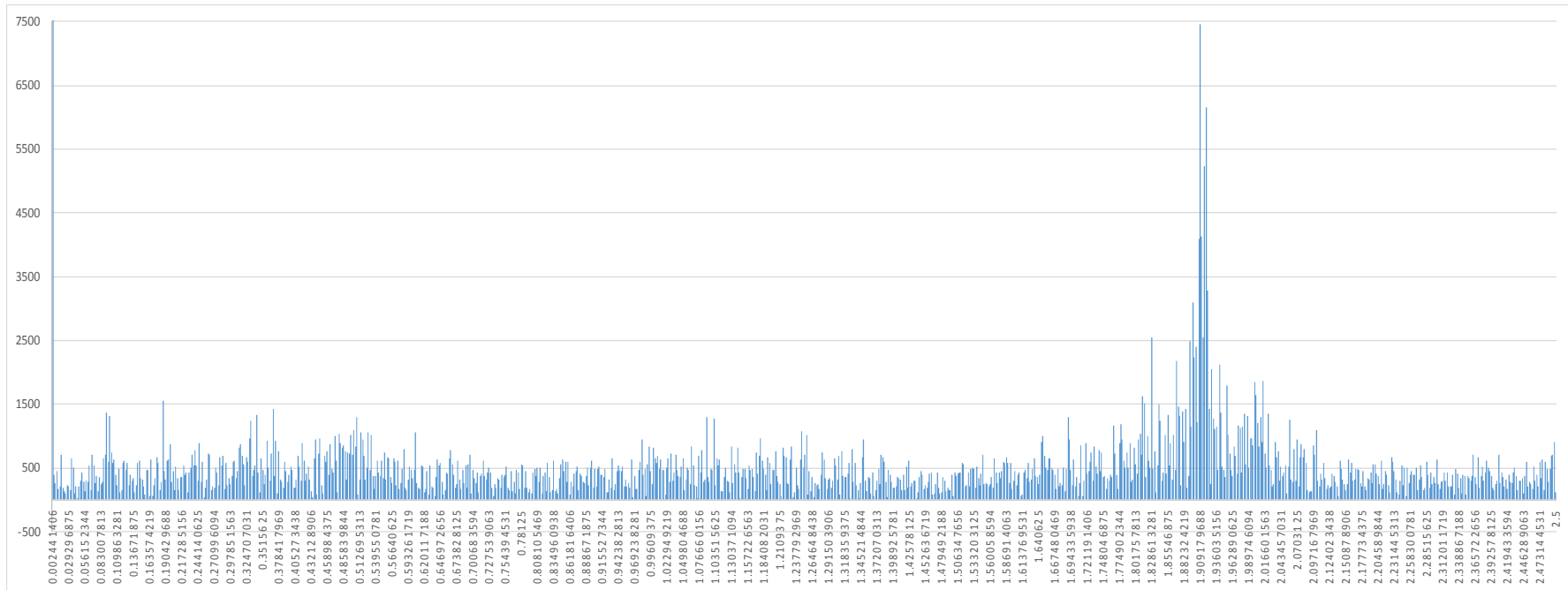
Engineering Analysis: Auto-Driller

What is going on at the edges of this scatter plot?

Finding new ways to view and analyze data!



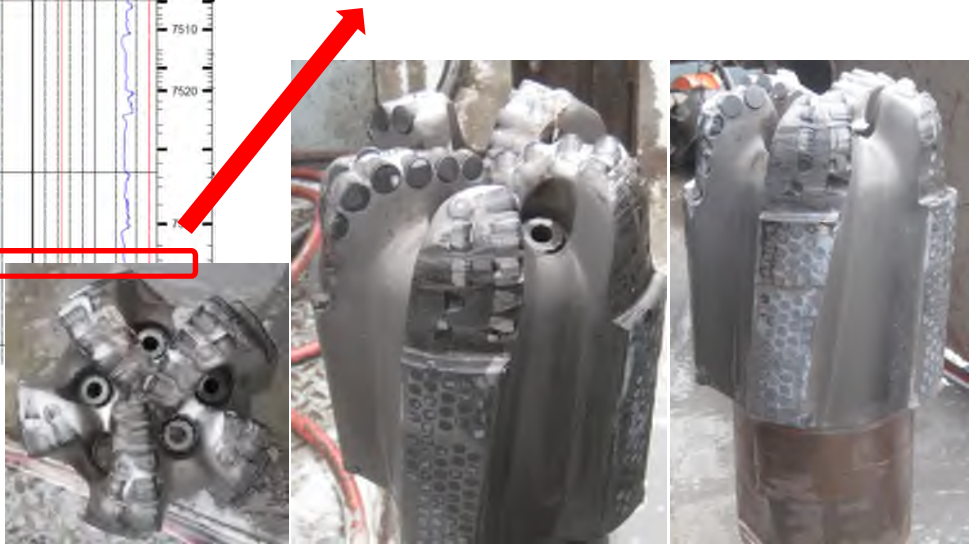
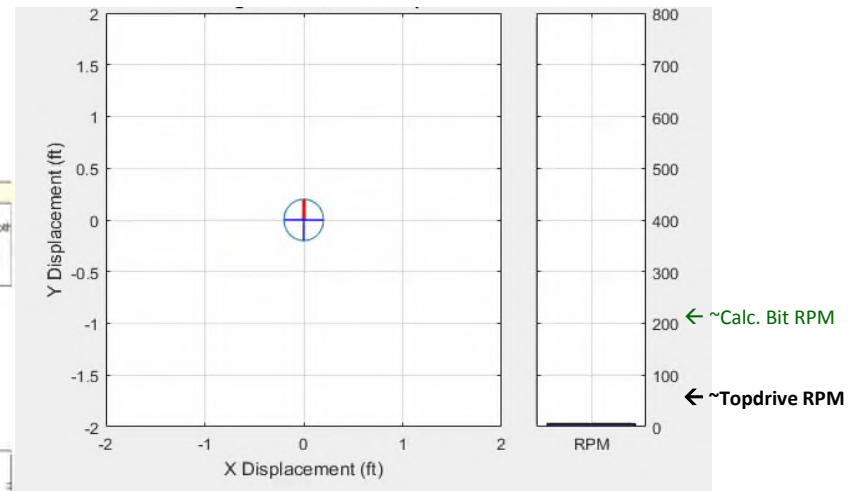
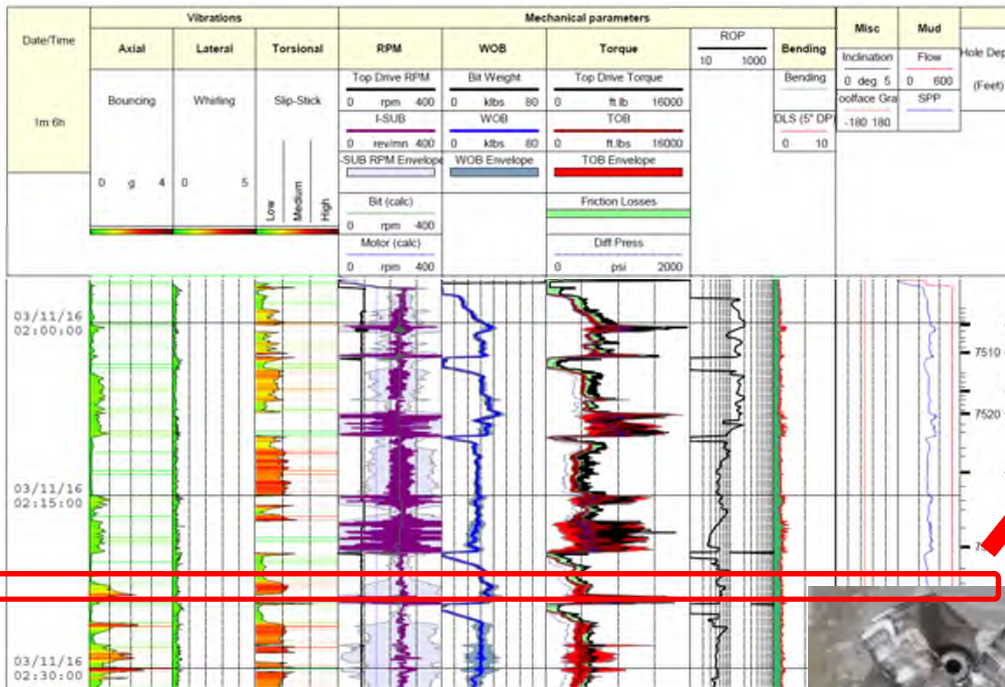
Engineering Analysis: Fourier Transform



Finding new ways to view and analyze data!

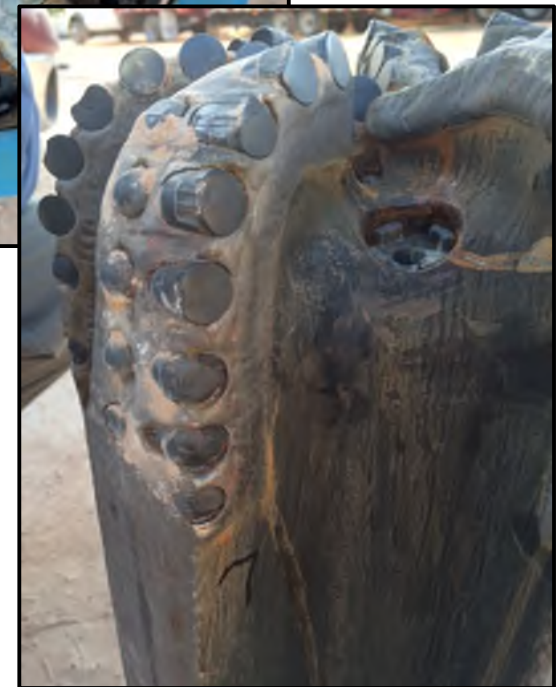
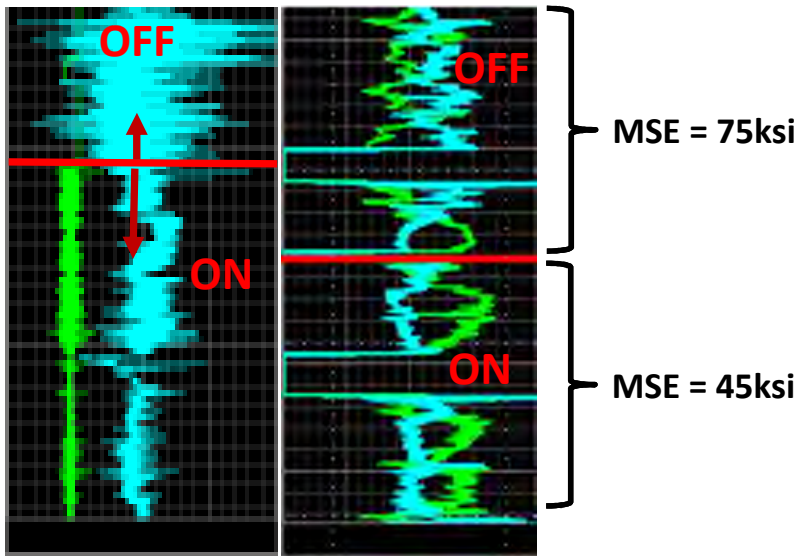
New Systems: Sensor above the bit (Stick-Slip)

Section / BHA: Vertical / Steerable Motor
Bit: 7-7/8" with 6" gauge



New Systems: Slip-Stick Control

Torque response
with & without
control system



Some Components of Implementation Program

- Training for Drilling Engineers
 - Bit design
 - Vibrations
 - Engineering analysis
- Drill Site Managers, contractors
- Continuous rig site support



Training: Advanced Bit Design

- Industry schools too basic
- Advanced PDC design concepts
 - Extended gauge length
 - Depth of cut control
- Drilling Engineer actions
 - Evaluate previous run
 - Evaluate damage
 - What to change - specifically?



Training: Vibrations

- Types of vibrations
- Source and how to mitigate
- Vibration modeling capabilities

DRILLING VIBRATIONS SEMINAR

Stu Keller
Central Drilling Group

Diagnosis/Mitigation of Whirl

- Diagnosis**
- Erratic, spiky MSE
 - MSE reduces with increased WOB and/or reduced RPM
 - Damage/wear to outside cutters of bit

• on BHA components
 • as rock hardness increases
 • in laminated rock due to cutter load

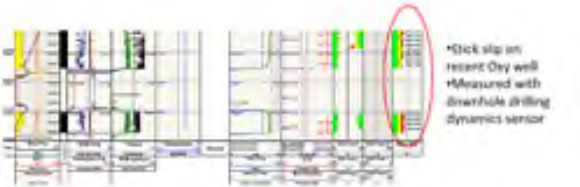


Photos of Likely Vibration-Related Failures



- **WOB/reduce RPM**
- **with low RPM, quickly go to full WOB, raise RPM (don't "feather" the bit)**
- **stabilizers with roller reamers**
- **critical rotational speeds**
- **over-gauge bits and add depth-of-cut elements for heterogeneous rock**

Stick-Slip: Downhole RPM Often Much Higher Or Lower Than Surface RPM



Training: Rig Site

- All rigs, multiple visits
- Workshops, rig floor
- Drill Site Managers, drillers, directional drillers

Drilling Dynamics Optimization Guidelines

This slide provides a comprehensive overview of drilling dynamics optimization. It includes sections for:

- Drilling Vibration:** Discusses the impact of vibration on drilling performance and bit life.
- Drilling Parameters:** Lists key parameters such as RPM, WOB, and DOC that influence drilling dynamics.
- Drilling Performance:** Explains how optimized parameters lead to higher drilling rates and reduced bit wear.
- Drilling Bit Life:** Details how minimizing vibration and optimizing parameters extend the life of the drilling bit.
- Drilling Costs:** Shows how optimization reduces overall drilling costs by improving efficiency and reducing bit consumption.

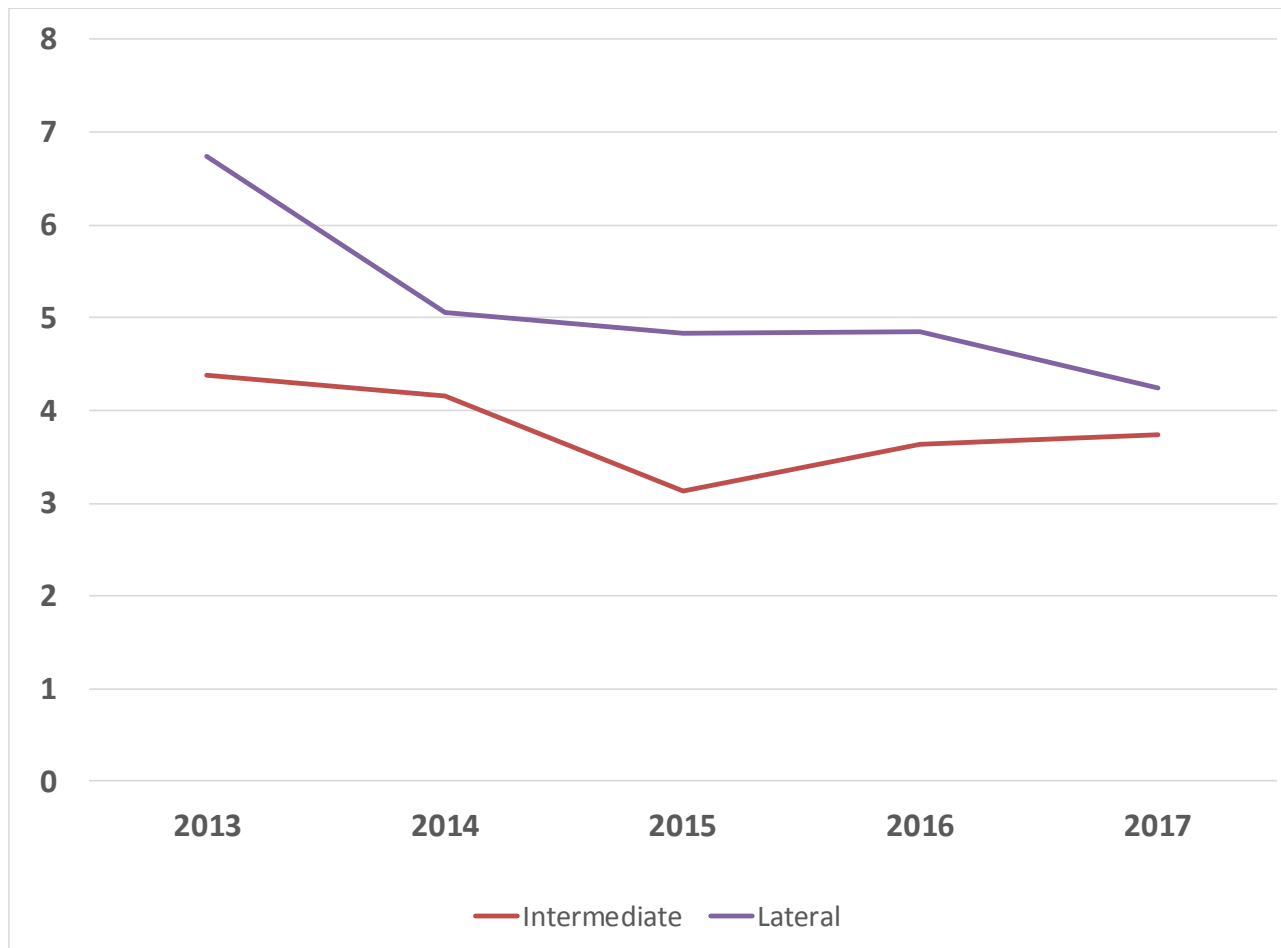
 The slide also features several graphs and diagrams illustrating the relationship between drilling parameters and performance metrics.

Feathering the bit
Why is it a poor practice?

This slide explains why feathering the bit is a poor practice. It includes:

- Likely Vibration-Related Failures:** Images showing bit failure modes such as bit chipping, bit failure, and bit failure.
- MSE vs. DOC Chart:** A graph showing Mean Squared Error (MSE) versus Drilling Onset Current (DOC) in revolutions. The chart is divided into three regions:
 - Stick slip (high DOC):** High MSE at high DOC.
 - Stable drilling (designed DOC):** Low MSE in the middle range.
 - Bit feathering zone (very low DOC, MSE off chart):** High MSE at very low DOC.
- Takeaways:**
 - Avoid feathering the bit.
 - Very high MSE
 - Bit life reduced
 - Quickly add WOB when resuming drilling after connections.

Bits per 10K Feet



Bits Then and Now



Then:
Slow ROP,
Short life



Now:
Fast ROP,
Short life

Complications

- Hard formations
- Laminated formations (“interfacial severity”, stick-slip)
- Directional paths (back-build, anti-collision)
- High-pressure flows, injection zones
- Drawn-down formations
- ROP control for rotary-steerable performance
- Tool-face control for steerable motors

Still potential for significant performance improvement!

