Permian Bain Case Studies related to Overall Cumulative Curvature

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Speaker Bio

- 25+ Yrs Experience (10 yrs Occidental & 15 yrs Scientific Drilling Intl.)
- Principal | Sr. Engineering Consultant Drlg
- Leader of the Oxy Wellbore Placement Community of Practice
- Chair – Operator's Wellbore Survey Group (OWSG)
- Univ. Louisiana Lafayette / BS Mechanical Engineering (1995)
- Specialized experience in
  - Directional Drilling Engineering
  - Wellbore Positioning & Trajectory Quality Metrics
  - Physics-Based Modeling (Hookload, Torque, Pressure)
  - Performance Drilling (Leader of Oxy' PerfDrlg CoP)
  - Advanced Wellbore Survey Practices & Technology

Agenda

- Introduction
- Curvature, Tortuosity and Undulation
- Surface Intermediate Curvature
- Curve & Lateral Curvature
- Case Study Examples (Good – Avg – Bad)
- Summary, Conclusions, and Q&A

Dogleg Severity

Dogleg Severity is a measure of the amount of change of inclination and/or direction of a bore hole. It is expressed in either degrees per 100 feet (°/100') or degrees per 30 meters (°/30m) of course length. Course length is the distance between surveys.

Several formulae are available to compute the total effects when there is a change in both inclination and direction between survey points. In the following formulae:

Dogleg severity (DLS) = $\{\cos^{-1}[(\cos I_1 \times \cos I_2) + (\sin I_1 \times \sin I_2) \times \cos(A_2 - A_1)]\} \times (100 \div MD)$

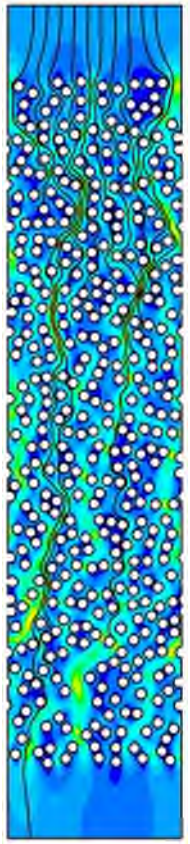
- I_1 = Inclination at Survey point 1
- A_1 =Azimuth at Survey point 1
- I_2 =Inclination at Survey point 2
- A_2 =Azimuth at Survey point 2

- The above formula is commonly used in estimating fatigue and strength criteria for tubular goods. It makes no assumptions about the well path and is therefore independent of survey calculation methods. Always Positive (Never Negative – It is an absolute value)

Absolute Value Always Positive – True value is Negative – Often a Bad Metric

Tortuosity

- What is Tortuosity?
  - Tortuosity is a property of a curve being tortuous (twisted; having many turns). There have been several attempts to quantify this property. Tortuosity is commonly used to describe diffusion and fluid flow in porous media, such as soils and snow.



Ref: https://en.wikipedia.org/wiki/Tortuosity

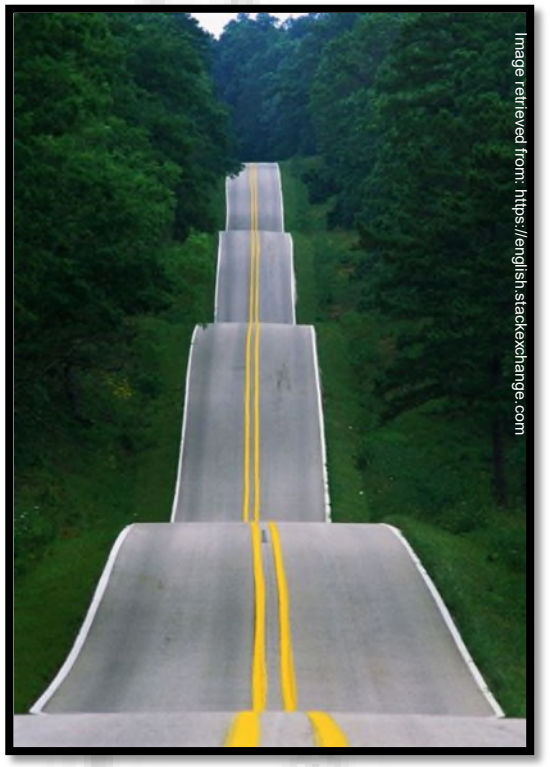
TORTUOSITY

- Does your lateral look like this?
- Does it Matter?
- What about the Surface and Intermediate?
- Why is it important to achieve exceptional steering control?
- Is the best smooth wellbore one that is not steered?
- Should we steer 100% of the lateral or should we focus steering only when needed.

TORTUOSITY UNDULATIONS

- What is meant by Undulations in a Lateral?
- How can you measure it?
- Does it affect production?
- Does it impact drilling?
- Does it affect the cement job and zonal isolation?
- Does this affect the quality of Stimulation
- How about Production? $$$

Vertical Undulation



Lateral Undulation

Undulating Tortuosity

- Zonal Isolation?

Image Extracted from:
http://www.engineerlive.com/content/22351

http://www.engineerlive.com/sites/engineerlive/files/styles/article/public/Pic2_HR_0.jpg?itok=FJx4KlSd,
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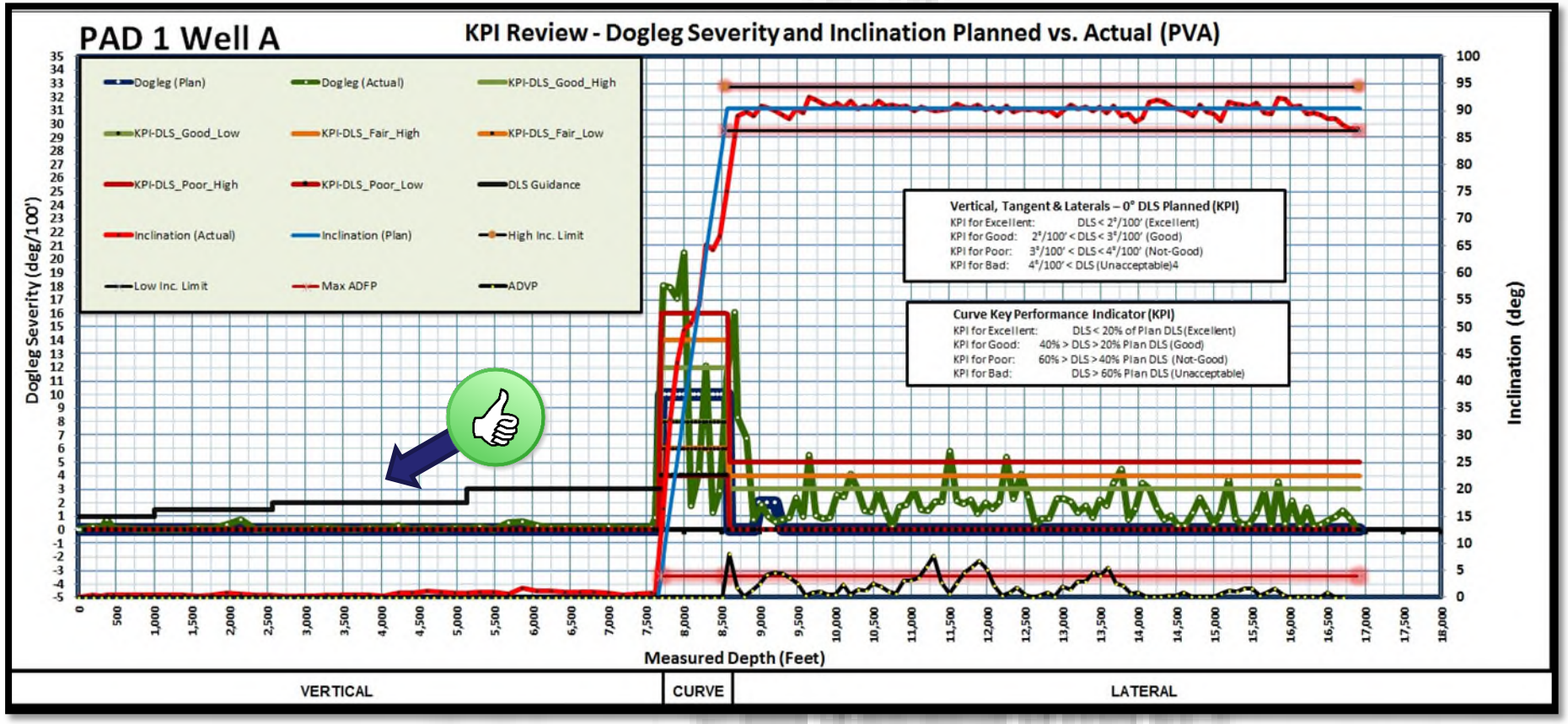
Tortuosity: Essentially "Unwanted Curvature"

- What does Unwanted Curvature look like?
  - Surface
  - Intermediate
  - Curve
  - Horizontal



Calculating High Side and Lateral Tortuosity

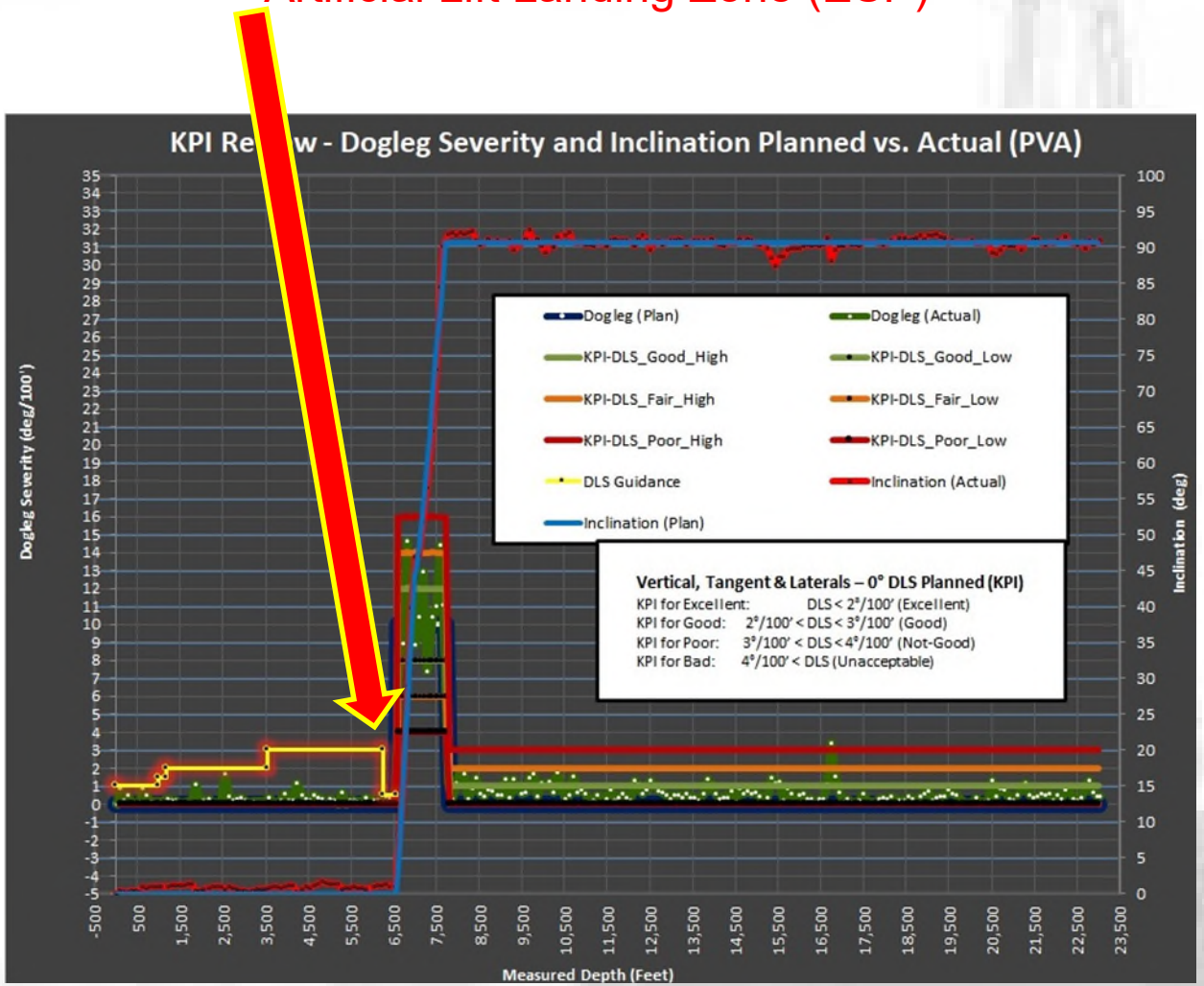
- Calculate Build Rate and Turn Rate for each interval
- Convert Turn Rate to Lateral DLS (Effective Turn Rate)
- ETR = Turn * sin (inclination) (Use average inclination for interval)
- Calculate δBR and δETR from one interval to next (as absolute values)
- Total Build = Σ BR x δMd Unwanted build = Σ .5 x δBR x δMd
- Total ET = Σ ETR x δMd Unwanted ET = Σ .5 x δETR x δMd
- High Side Tort Index = Unwanted Build / (Total Build – Unwanted Build)
- Lateral Tort Index = Unwanted ET / (Total ET – Unwanted ET

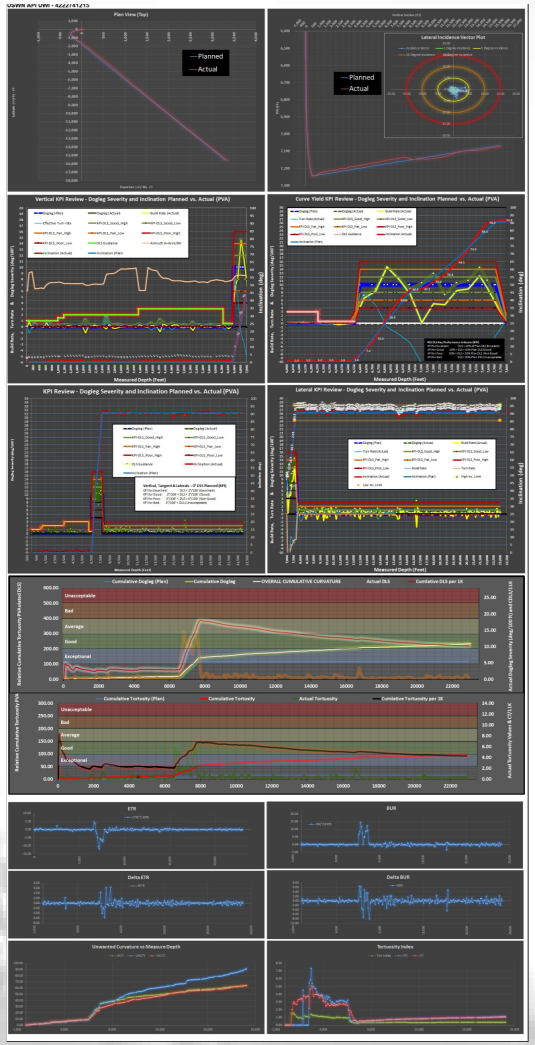
DrillingMetrics (iscwsa.net) - https://www.iscwsa.net/media/files/files/5501ff32/10-iscwsa50-angus-jamieson-drlgmetrics.pdf

$$\text{Combined 3D Tortuosity Index} = \sqrt{(\text{Highside TI})^2 + (\text{Lateral TI})^2}$$

Tortuosity: Essentially "Unwanted Curvature"

- What does Unwanted Curvature look like?
  - Surface
  - Intermediate
  - ALLZ (??)
  - Curve
  - Horizontal





Tortuosity: Essentially "Unwanted Curvature"

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ALLZ – a Stair Step in maximum allowable curvature or dogleg severity for artificial lift placement and operational efficiency (ESP and Beam Lift)

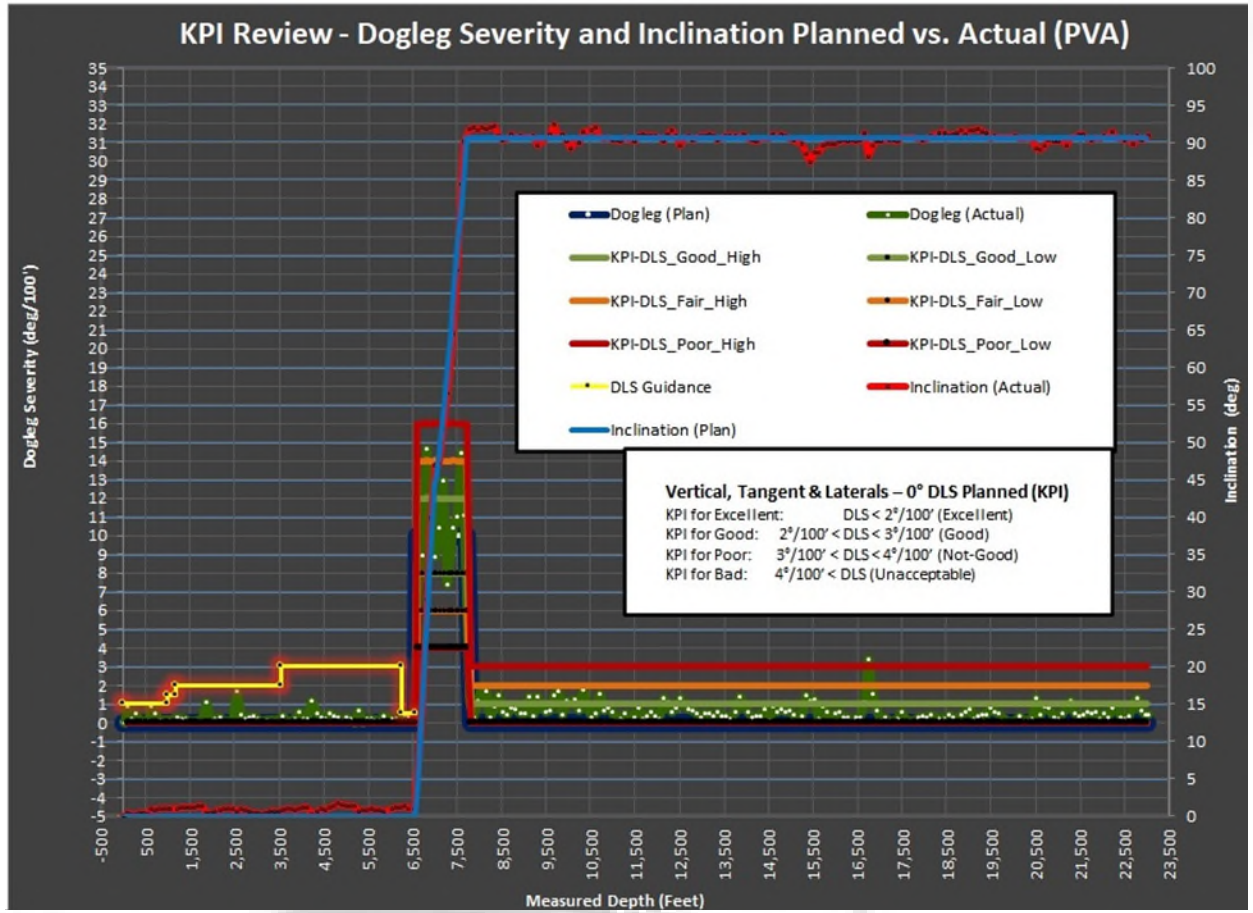
No Shallow Nudges!

Safe-Separation Directional Work as deep a possible!

Surface to 1,000' MD (Surface Interval)	*DLS < 0.5°*
2,500' MD (1K' MD to 25% of KOP)	*DLS < 1°*
2,500' to 5,000' MD (25% to 50% of KOP)	*DLS < 1.5°*
5,000' to 7,500' MD (50% to 75% of KOP)	*DLS < 2°*
7,500' to 10,000 (75% of KOP to the KOP)	*DLS < 3°*

Add a 200 ft Non-Steered Interval above KOP for ESP

DON'T KICK OFF EARLY!!!



ALLZ & CURVE KPI METRICS

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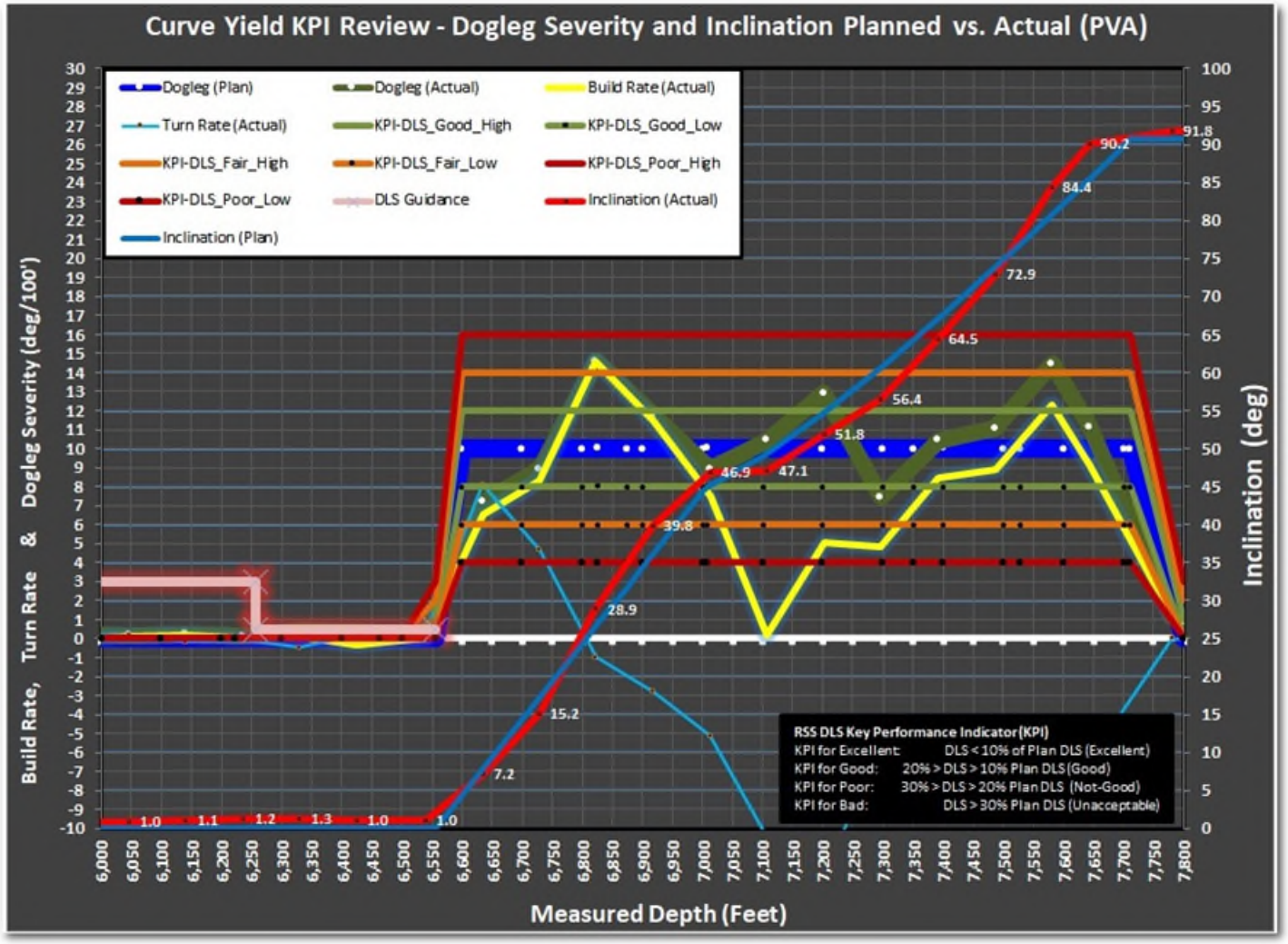
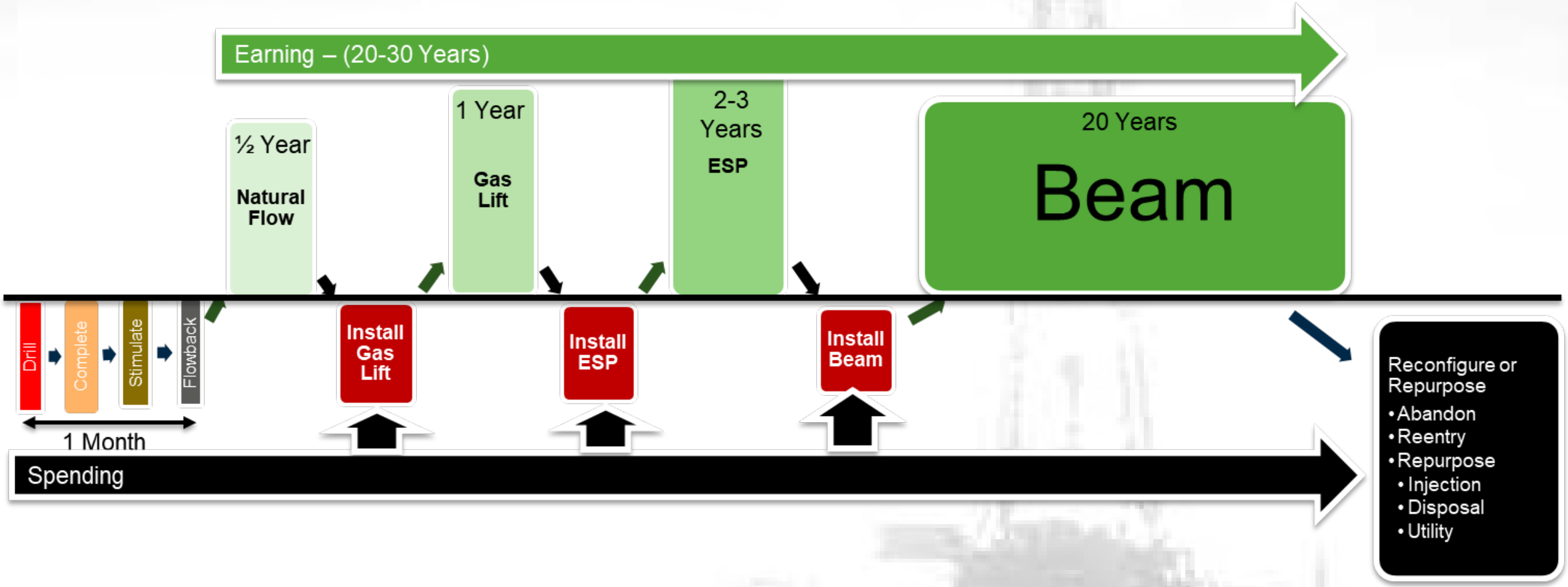
Question…

- How do you achieve a <0.5° DLS 200 ft interval before the KOP?

Directional Drilling Dogleg Severity Control Key Performance Indicators				
Directional Tools & Hole Section Type	Excellent	Good	Not-Good	Unacceptable RCRA Required
Vertical Intervals	DLS ≤ 2	2 < DLS ≤ 3	3 < DLS ≤ 4	4 < DLS
Tangent Intervals	DLS ≤ 2	2 < DLS ≤ 3	3 < DLS ≤ 4	4 < DLS
Lateral Intervals	DLS ≤ 2	2 < DLS ≤ 3	3 < DLS ≤ 4	4 < DLS
Directional Motor Steering Interval	DLS < +/- 20% of Planned DLS	Between 20-40% of Planned DLS	Between 40-60% of Planned DLS	DLS > +/- 60% of Planned DLS
Directional RSS Steering Interval	DLS < +/- 10% of Planned DLS	Between 10-20% of Planned DLS	Between 20-30% of Planned DLS	DLS < +/- 30% of Planned DLS



Tortuosity: Essentially "Unwanted Curvature"

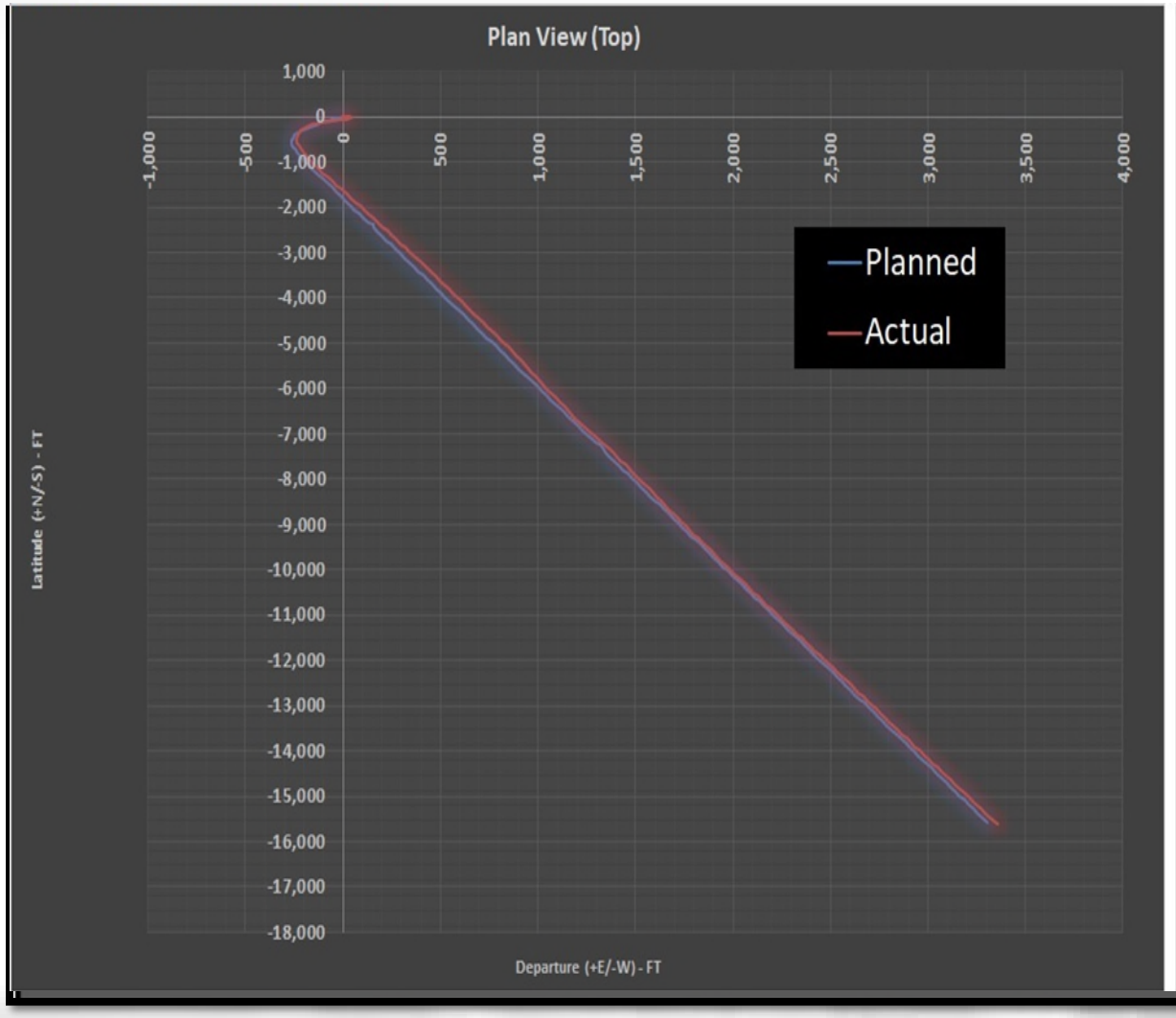


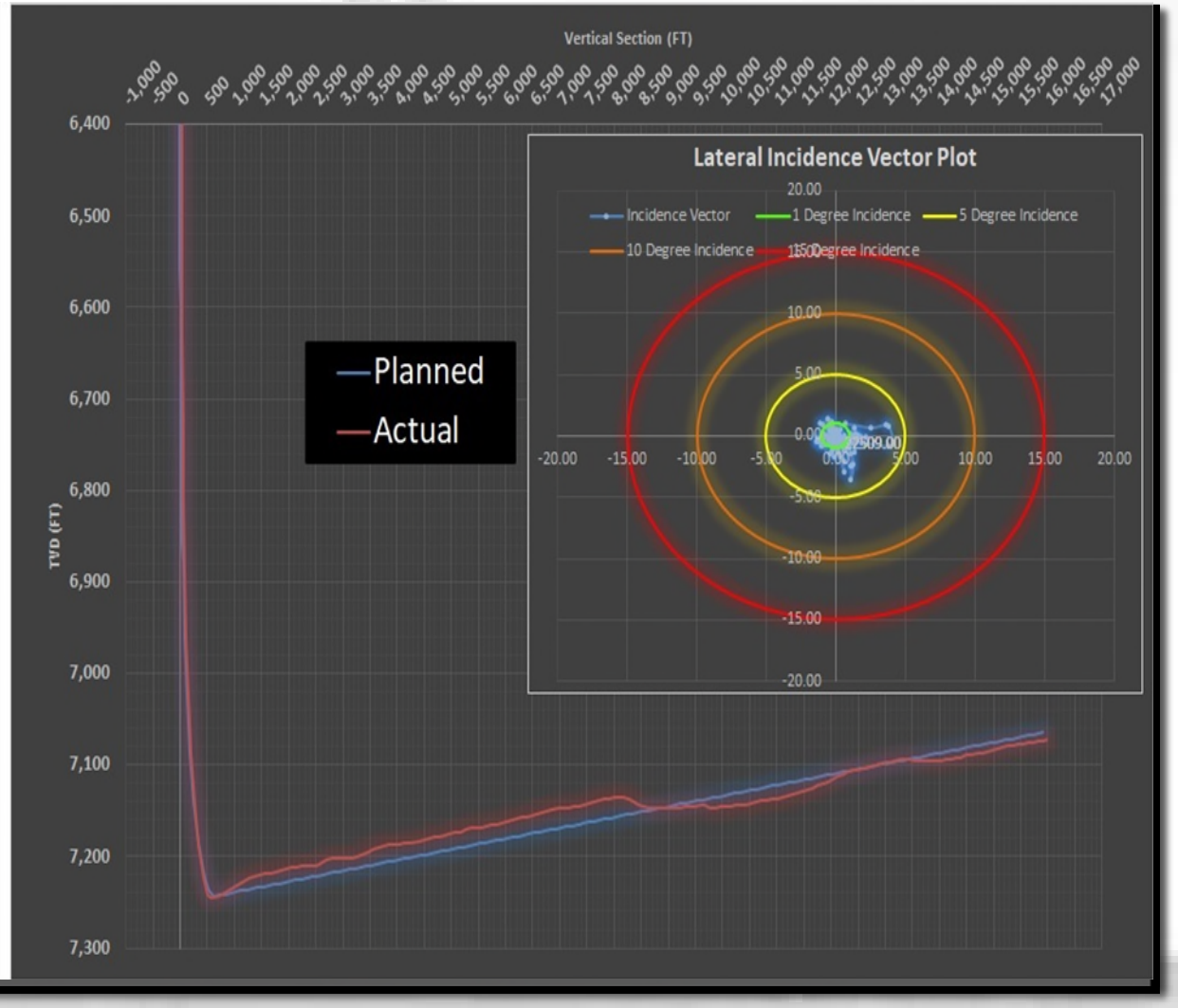
Cumulative Curvature (Normalized)

Like a traditional Cumulate DLS Calculation (Add up all the Doglegs)

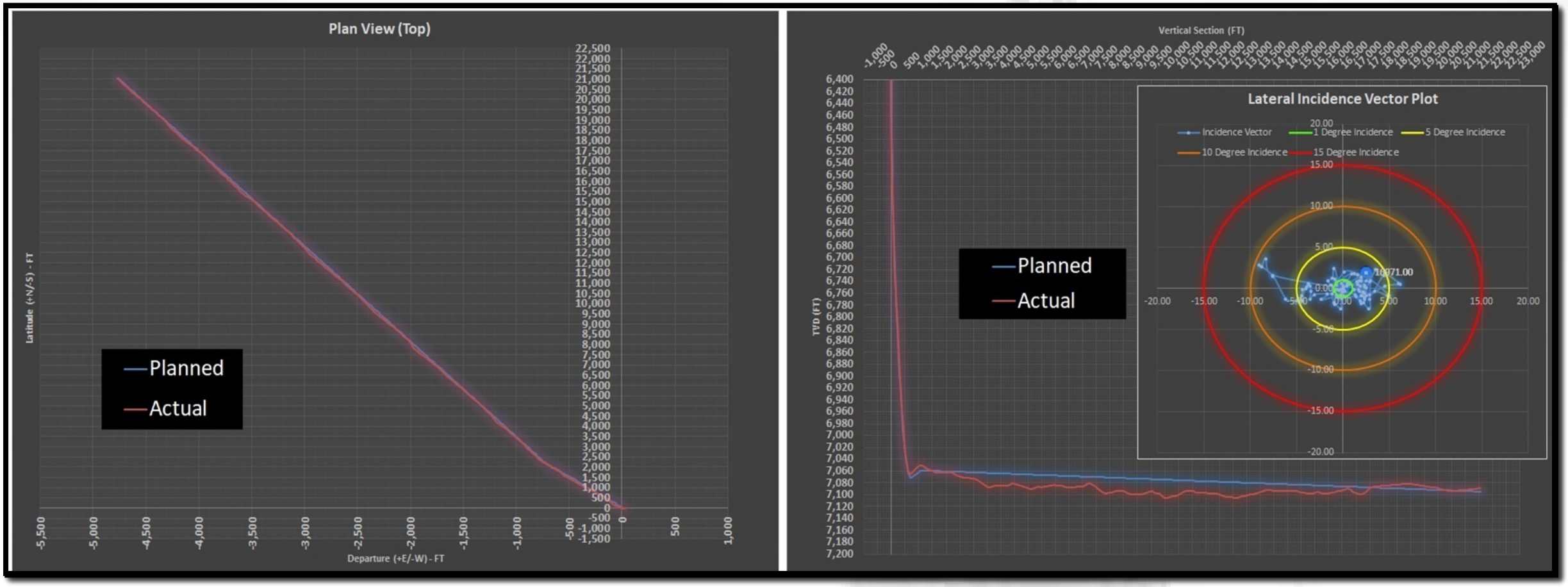
- Calculate Build Rate (BR) for each survey station
- Calculate a Turn Rate (TR) for each survey station
- Calculate the Effective Turn Rate [ETR = Turn * sin (inc)]
- Curvature = $\sqrt{}$SQRT ($ETR^2 + BR^2$)
- Interpolate the Survey in 20 ft Increments
- Add all the curvature and divide by 5 to normalize the data

Cumulative Curvature – Good Example (15,454 ft)

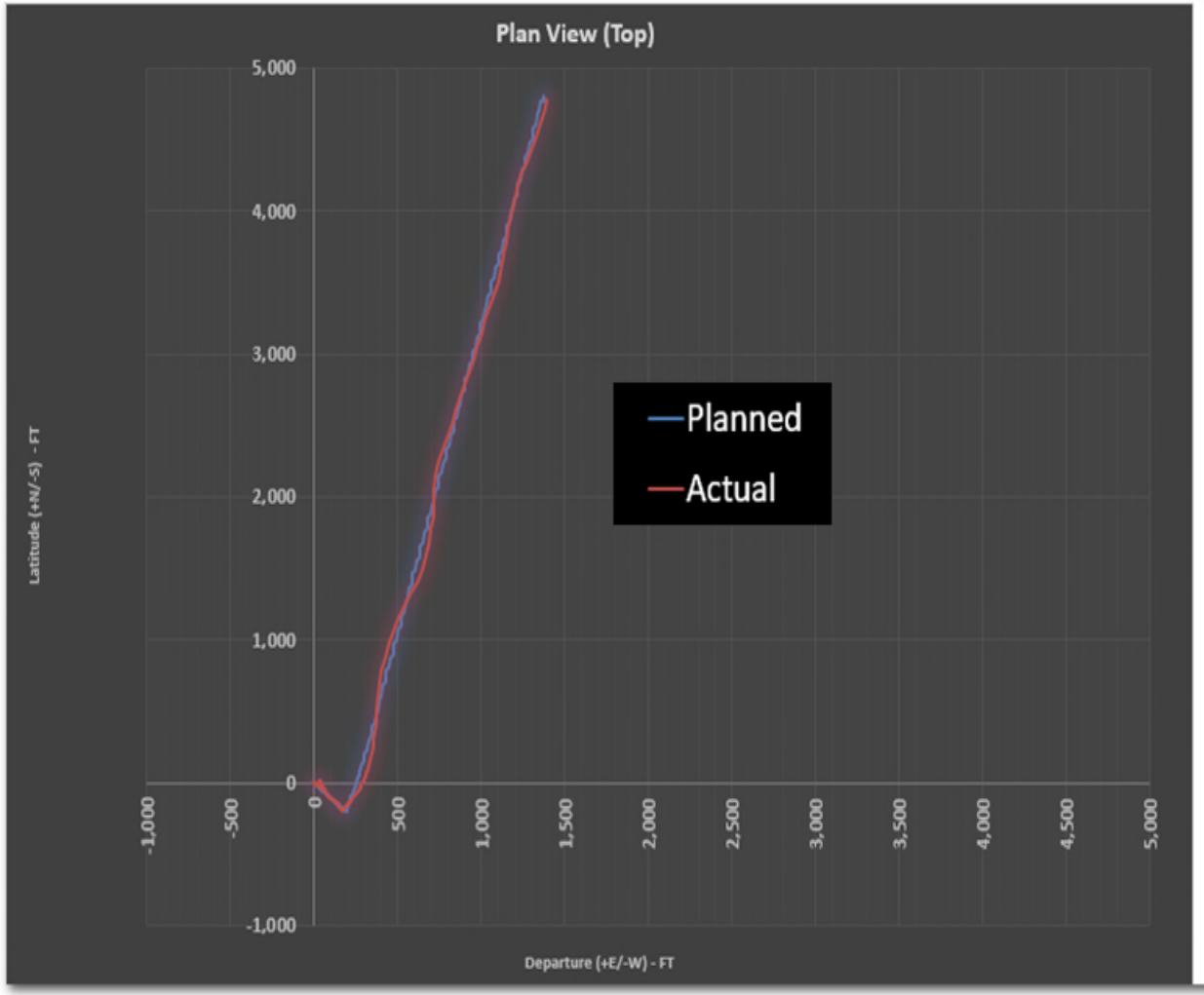


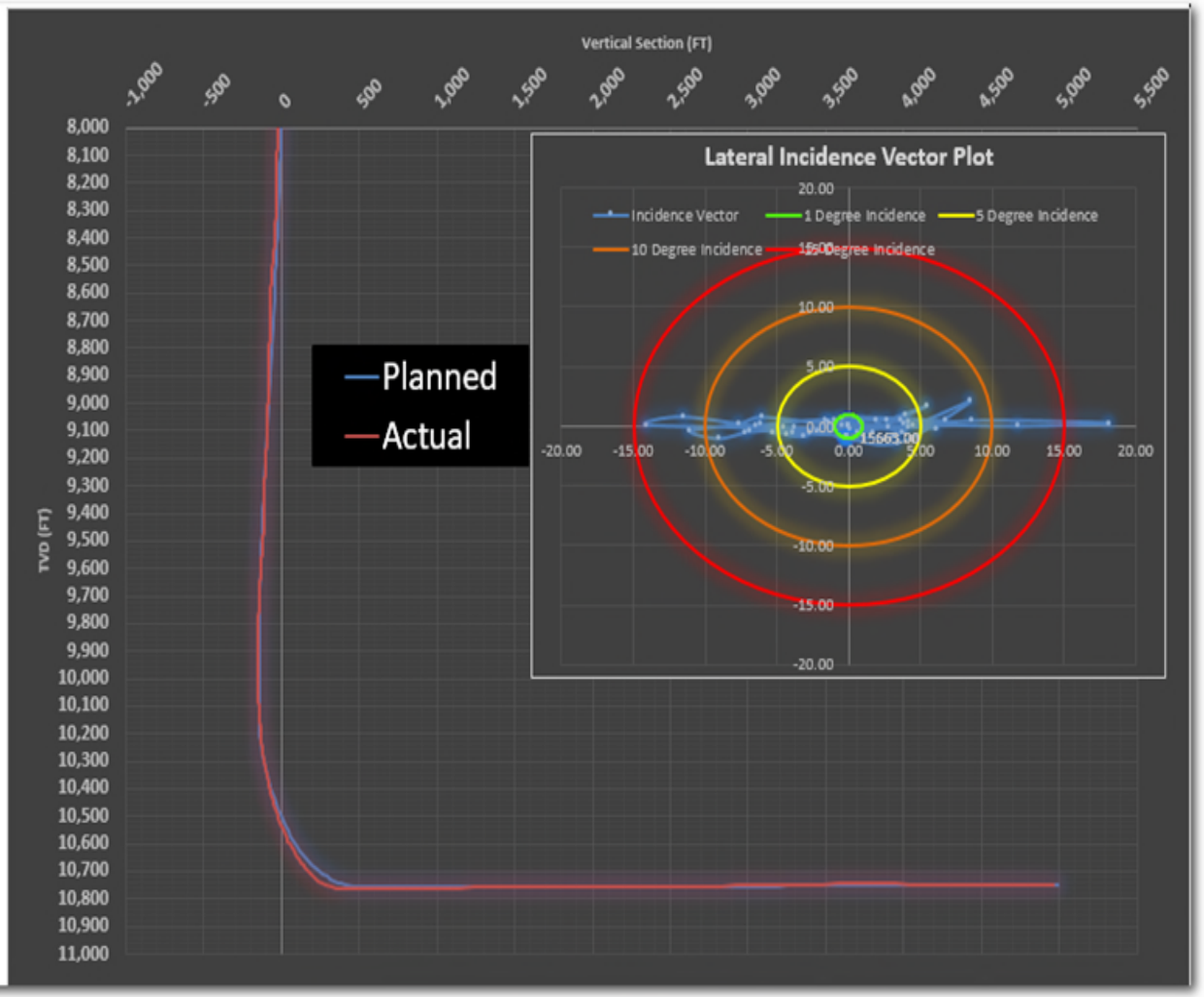


Longest Permian Lateral – Avg. Example (20,922 ft)

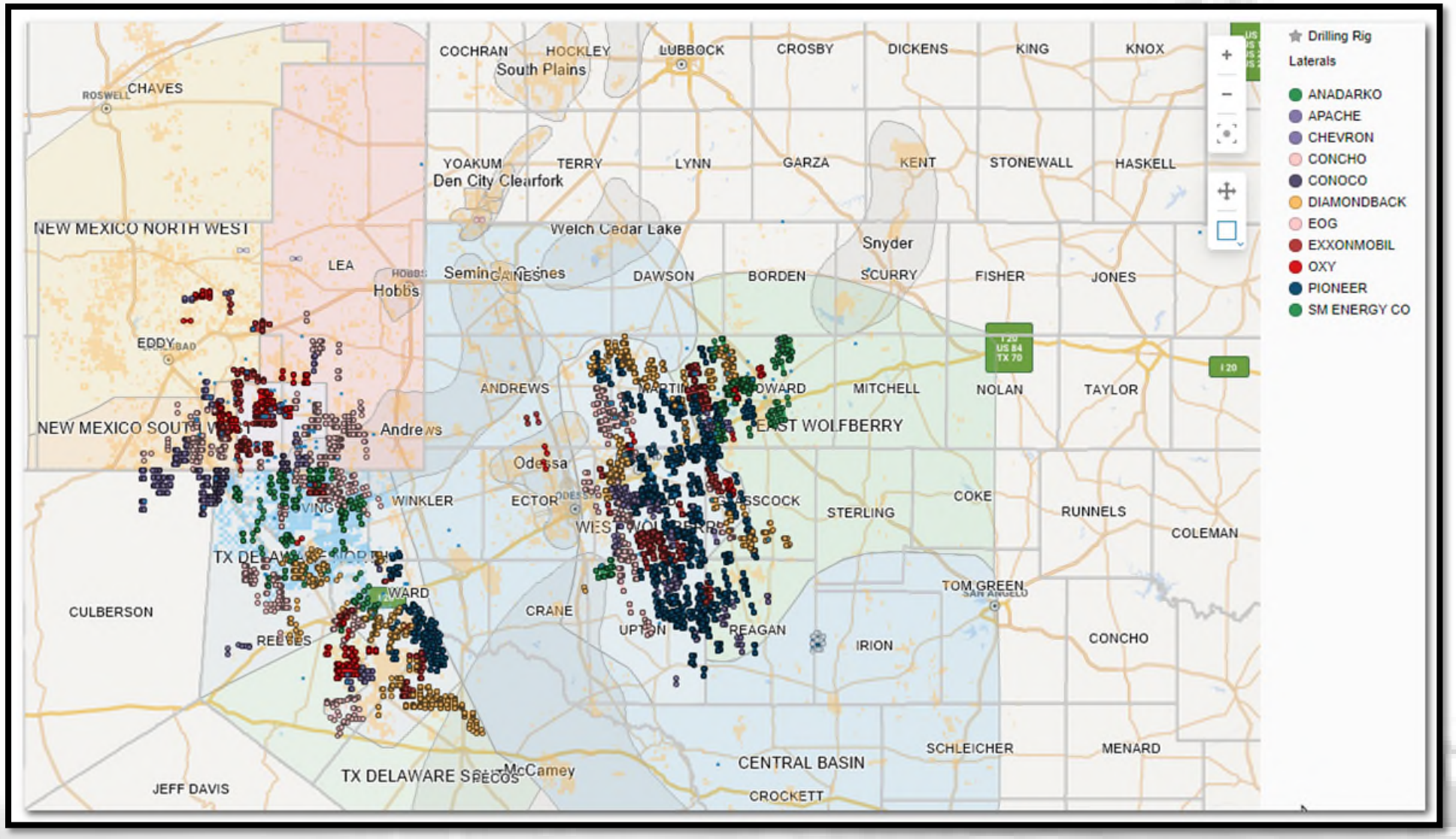


Short Delaware Lateral – Not Good Example (4,664 ft)





Permian Basin Curvature Study



2018-2021
Public Data

Permian Basin Curvature Study

2018-2021

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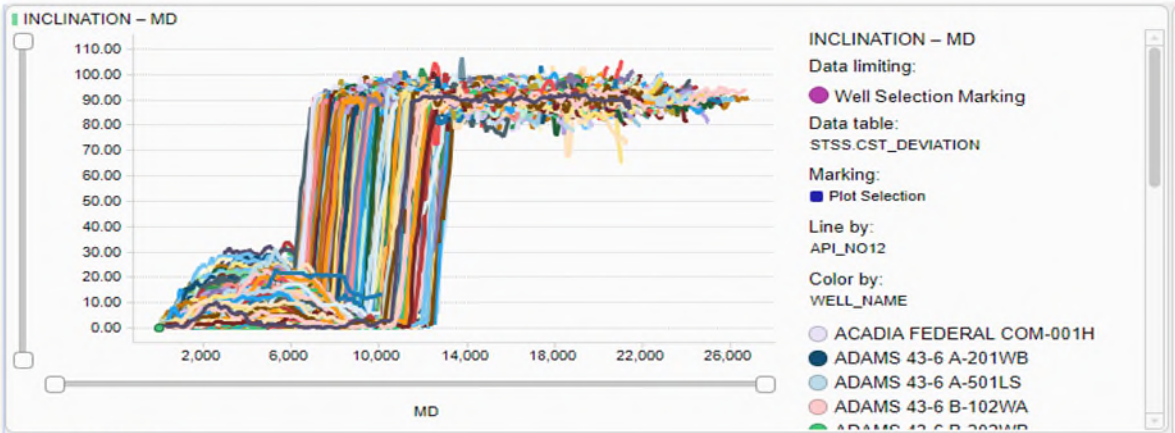
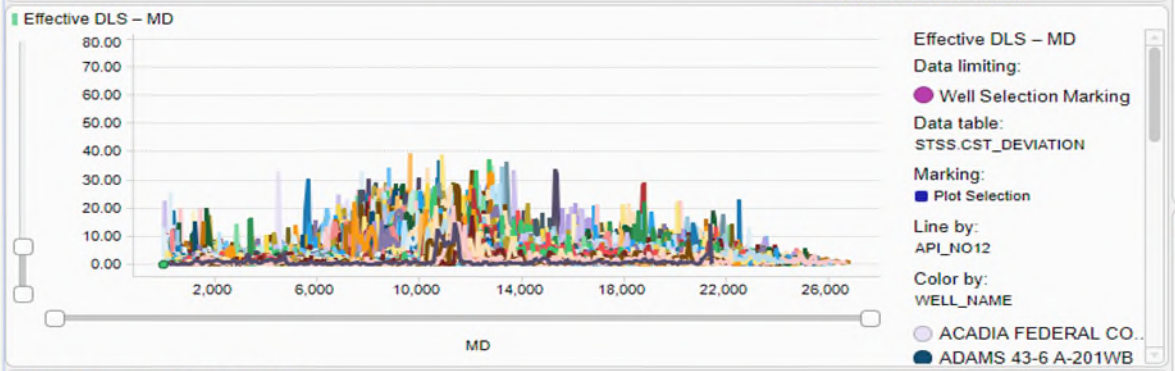
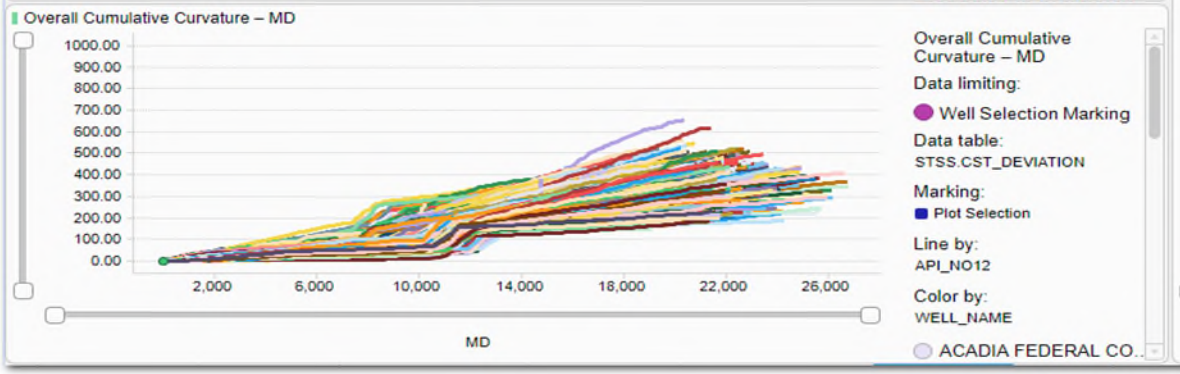
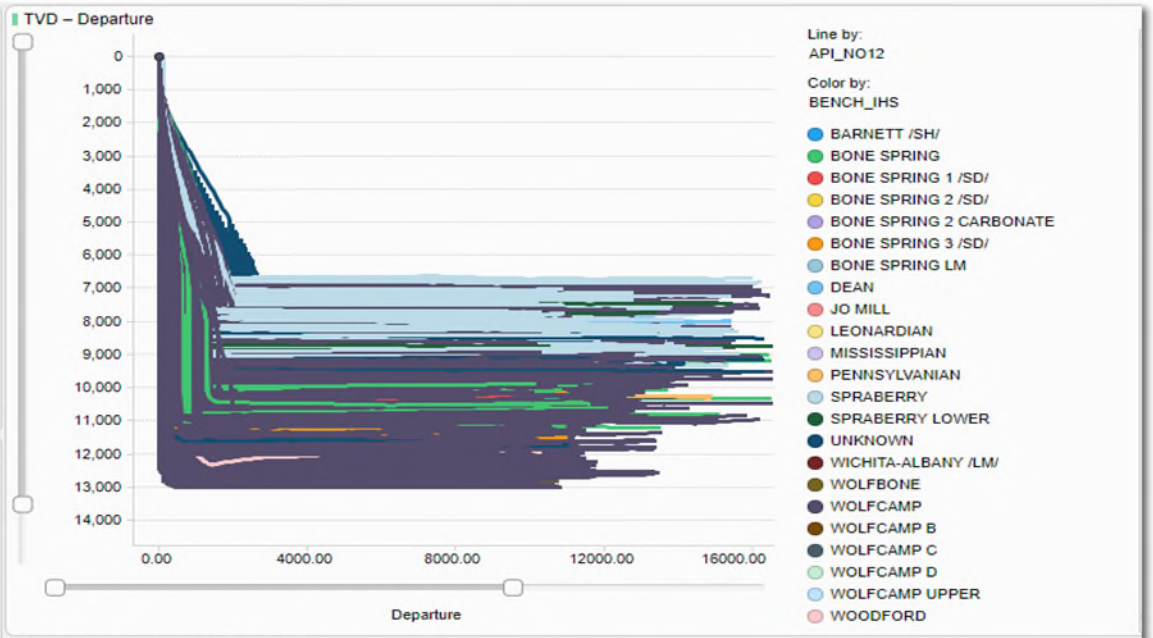
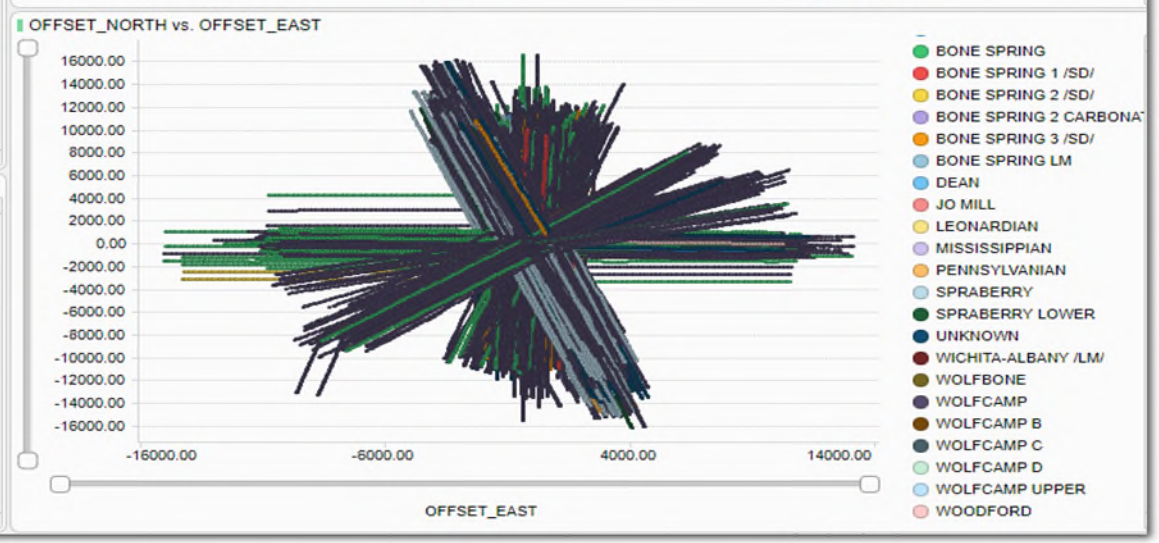


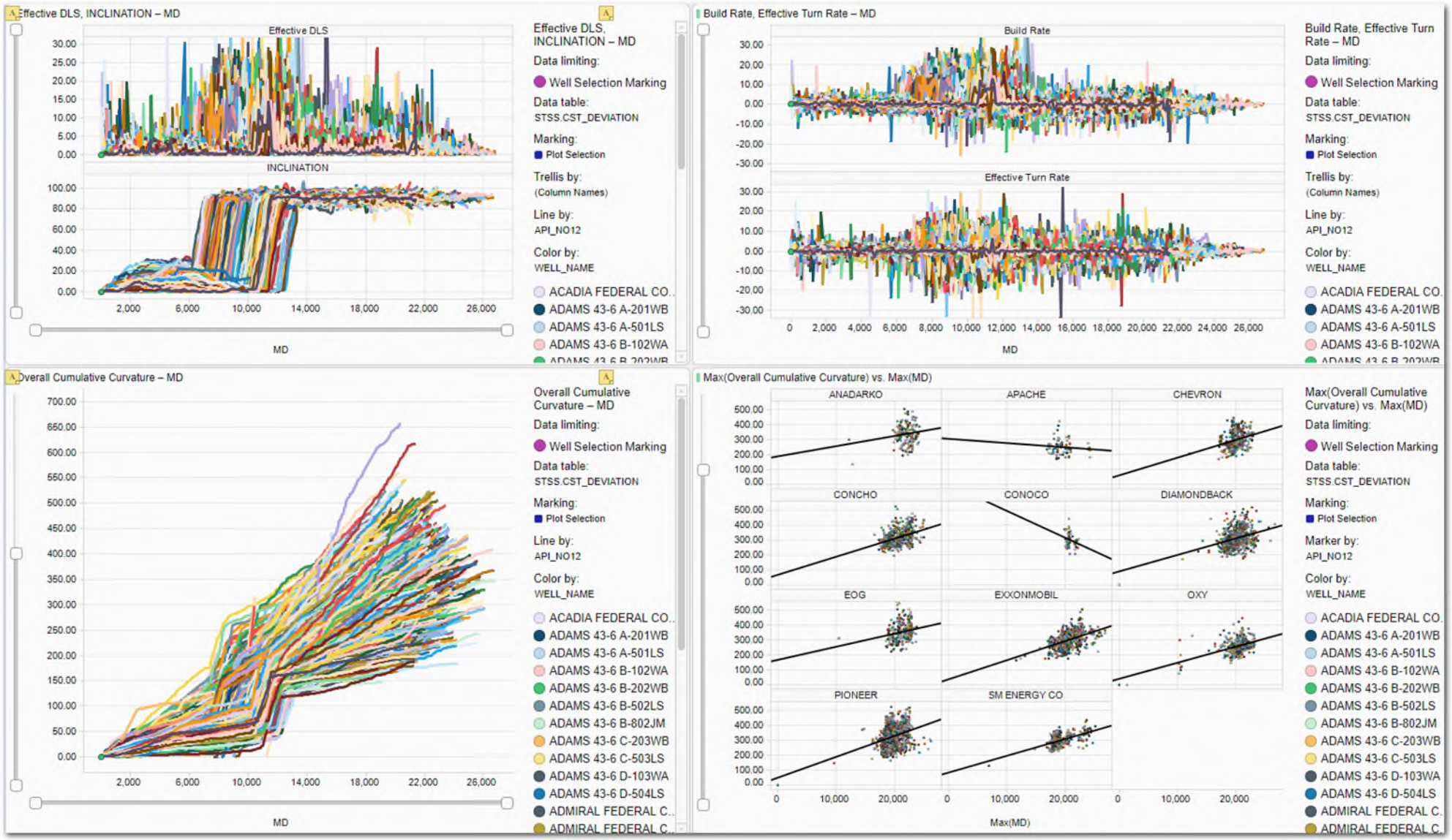








Permian Basin Curvature Study



2018-2021
Data: S&P Global

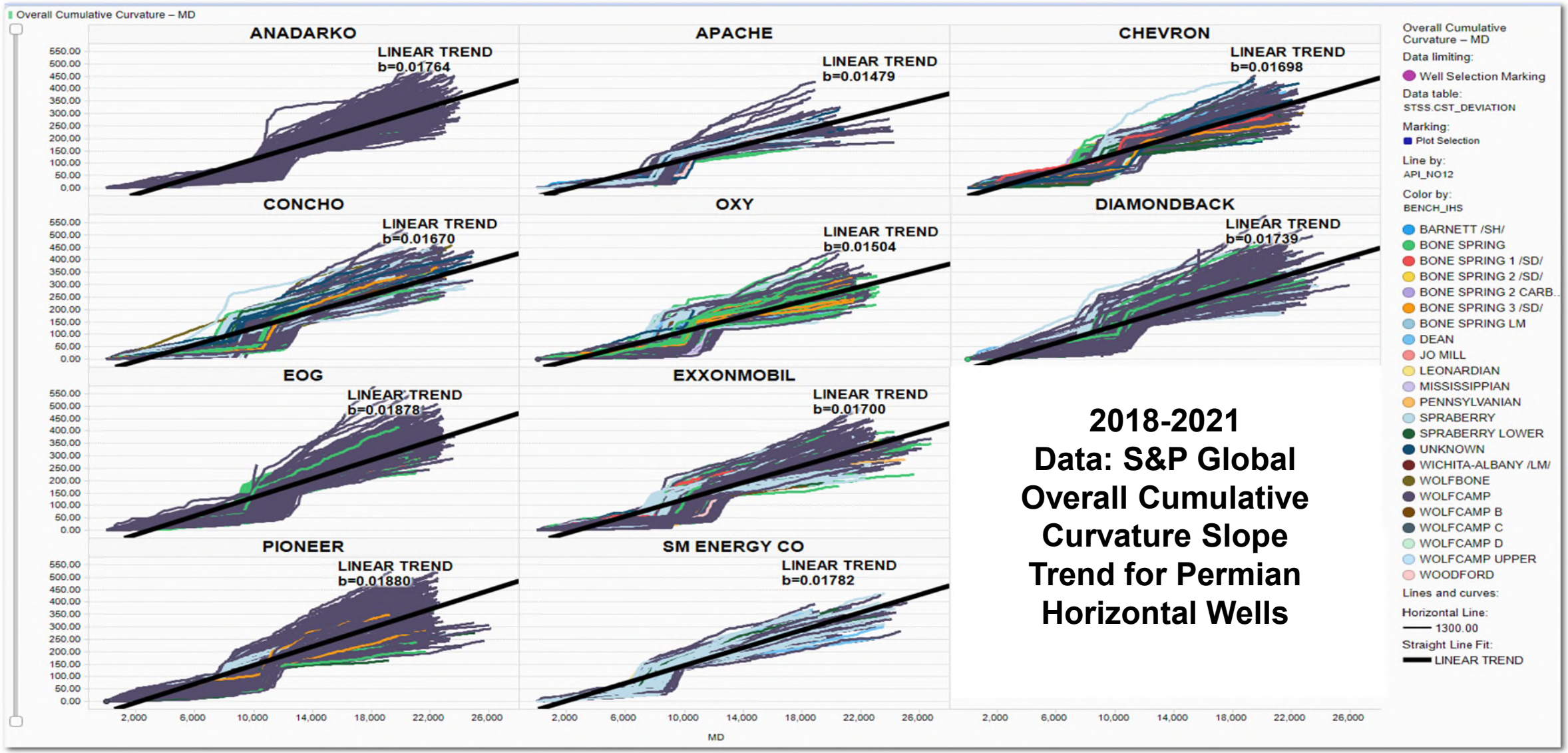
Overall Cumulative Curvature

MD vs. Inc
MD vs. DLS

Effective DLS
Build Rate
Effective Turn Rate
Curvature Slope

Trend for Permian Horizontal Wells

Permian Basin Curvature Study



Summary and Conclusions

- Steering as well increases overall cumulative curvature.
- The smoothest well interval is a not-steered, only steer when necessary
- Avoid shallow well nudges, corrections and planned inclination
- Stair-step the planning and executed curvature rate, consider deeper step-outs (back-builds & side-steps) where tension and sideloading is much lower
- Keep steerable motor bends as small as possible when motor steering
- Dial down the RSS pad-force or bit-point.
- No aggressive steering and take time to spread the minor deviation corrections over hundreds of feet
- Keep a lateral 1-2° up/down & left/right window prior to steering the lateral considering safe-separation and lease boundary rules. (Max +/- 4° from Plan)
- **PROPERLY STABILIZED DRILLING ASSEMBLY FOR STABLE DRILLING**
- **VERIFY WOB AND DIFF PRESSURE TARE**
  - **PLOT: HOOKLOAD + WOB (NORMALIZED HOOKLOAD)**
  - **PLOT: STANDPIPE PRESSURE – DIFFERENTIAL PRESSURE (NORMALIZED DRILLING PRESSURE)**

Thank You

Permian Bain Case Studies related to Overall Cumulative Curvature

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Robello Samuel (UH / Halliburton Fellow)

Ross Lowdon (SLB)

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- Deriving Wellbore Quality Metrics from Trajectory Calculations, by Angus Jamieson at the ISCWSA 50th Mtg. 03Oct2019
- OWSG (Operator's Wellbore Survey Group)
- ICSCWA (Industry Steering Committee on Wellbore Survey Accuracy)
- IADD Presentation: Jonathan Lightfoot, Oxy - Bullseye Presentation 2019 Pushing the Limits Topical Forum
- Directional Drilling Quality Metrics Workbook from Pete Clark (Posted on the OWSG Subcommittee Page
- OWSG Meeting Minutes 20 Slide Deck from the meeting on 28Sept2022
- AADE-22-FTCE-078 - Real-Time Drilling Hydraulics Advisory System: A Case Study – Ali Karimi, Jonathan Lightfoot, Qian Li, Reza Asgharzadeh, and Tatiana Gobert (Oxy)