Tortuosity

Angus Jamieson, UK Manager Helmerich & Payne

OUR WAY FORWARD, TOGETHER
100 YEARS
HELMERICH & PAYNE

Speaker Introduction

Angus Jamieson

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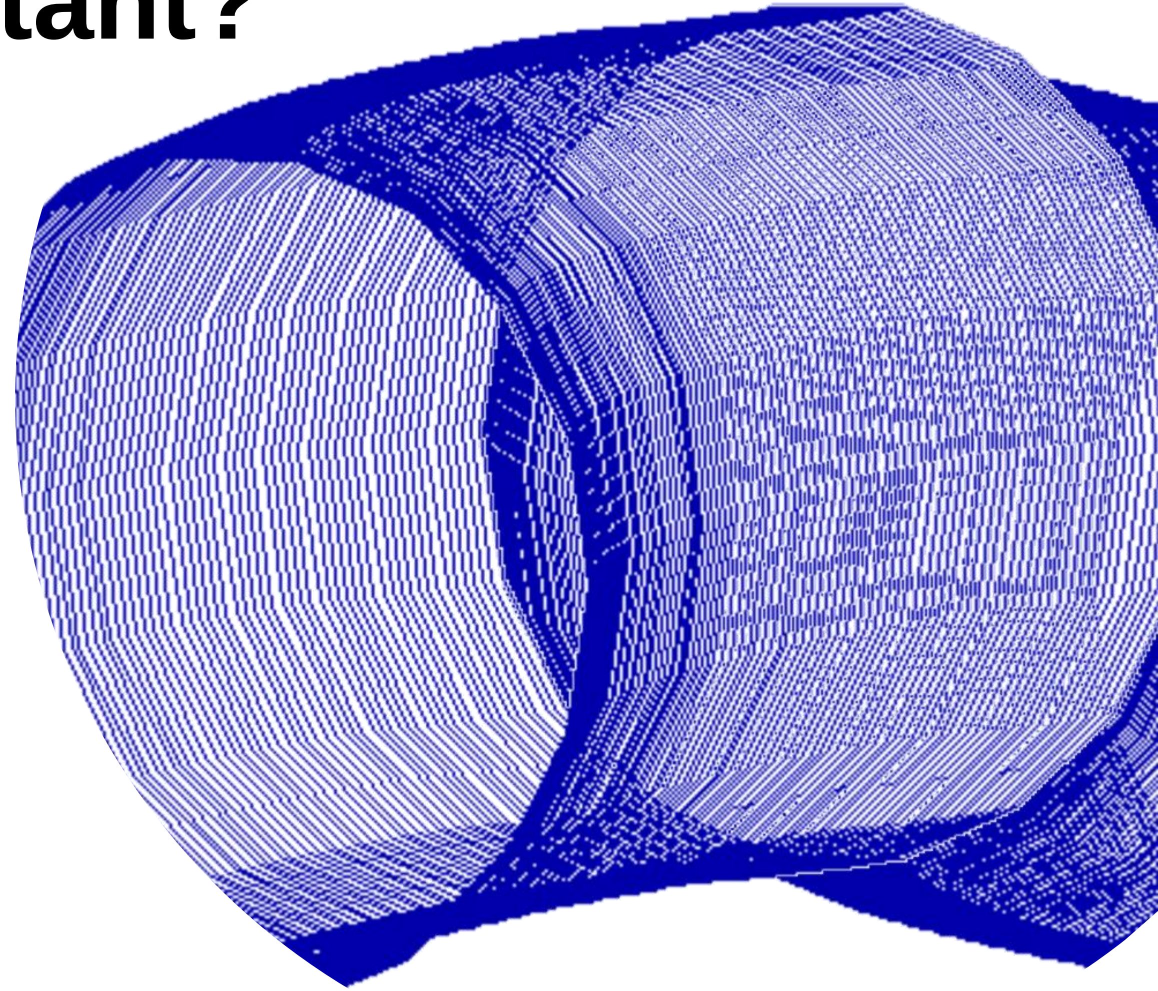
Technical Fellow and member of H&P Global Research and Innovation Team GRIT
40 years Offshore Drilling and Marine Operations
Directional Drilling Consultant and Trainer

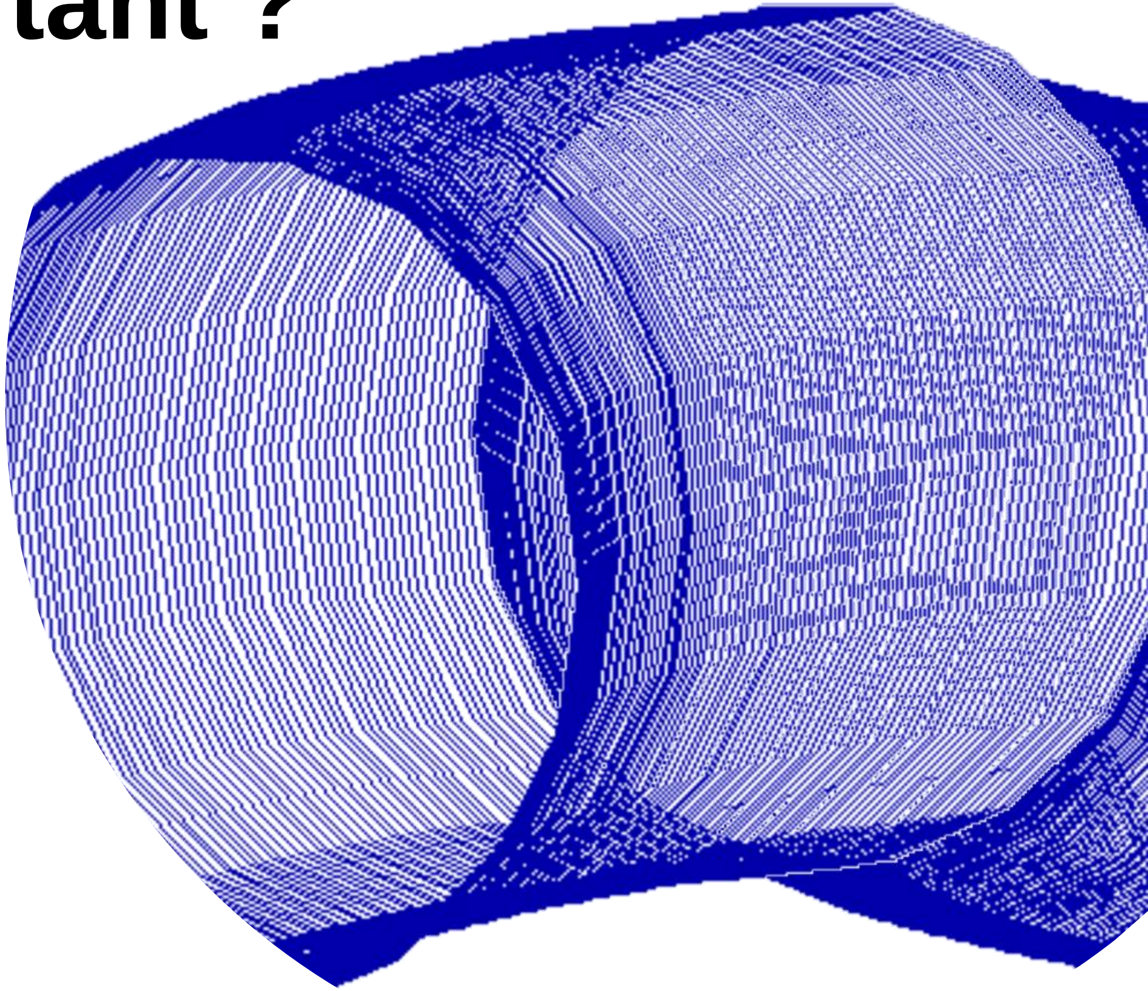
Why is tortuosity important?



1. It increases torque and drag while drilling
2. It reduces buckling resistance in drill pipe
3. It increases drillstring fatigue when rotating
4. It impedes hole cleaning while drilling
5. It increases drag when running casing
6. It compromises cement job quality

Why Tortuosity is Important ?

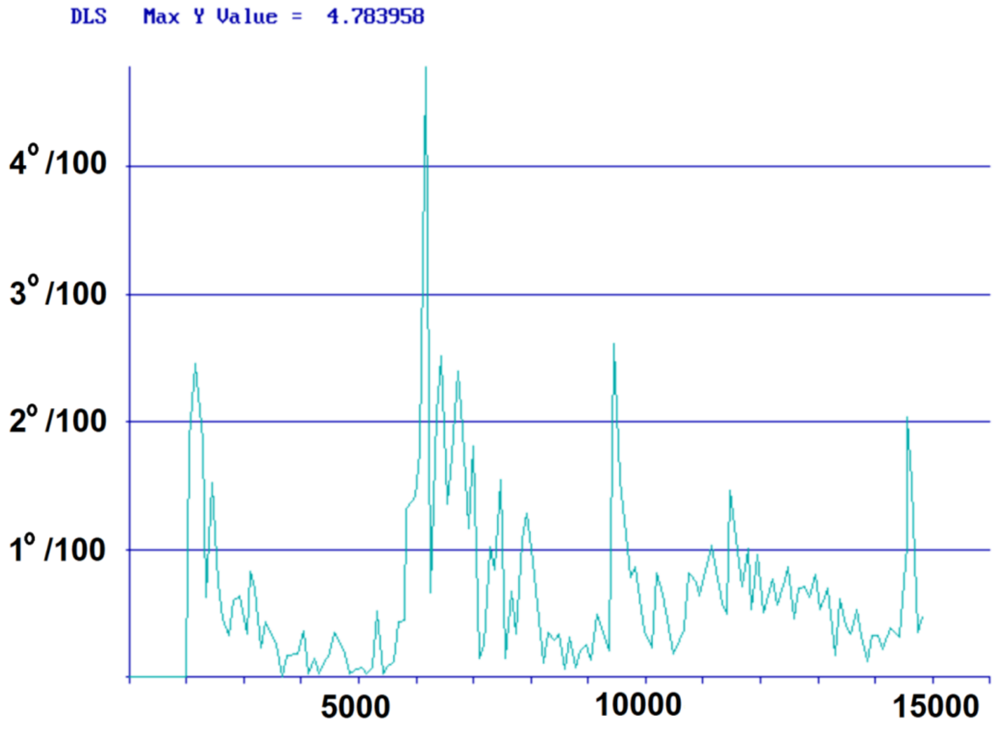
7. It causes variations in cross section due to cuttings traps and so..
8. It can effect production rate
9. It can reduce production quality
10. It compromises survey accuracy with the consequence that
11. It makes geo-steering more uncertain
12. It compromises geological modelling accuracy



Ways to Measure Tortuosity

DLS against MD

- Easy to calculate
- Uses survey data
- Easy to Understand
- The less you survey the better you look
- May miss key points
- No simple comparison



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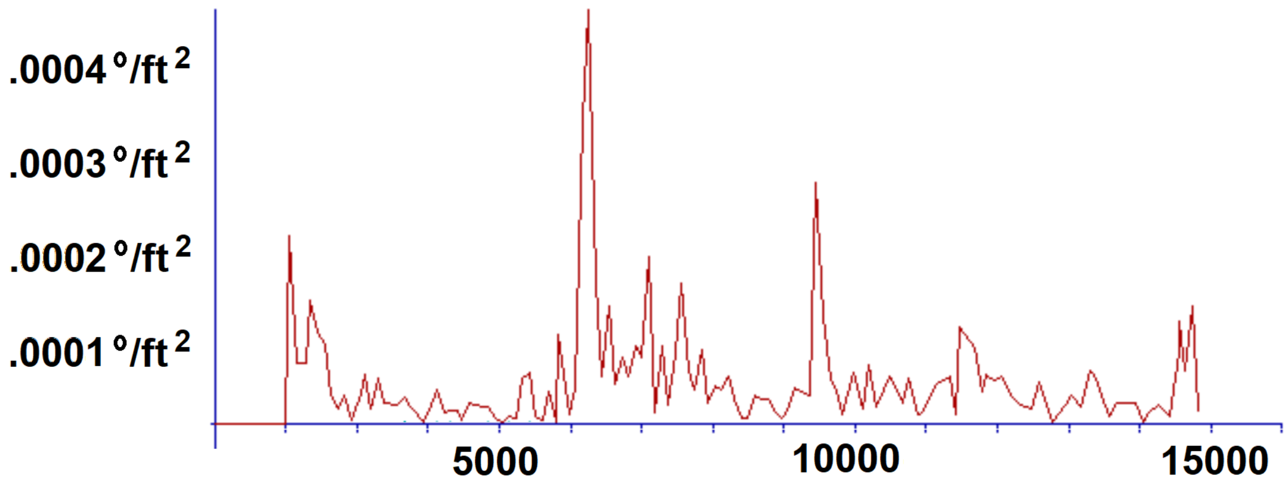
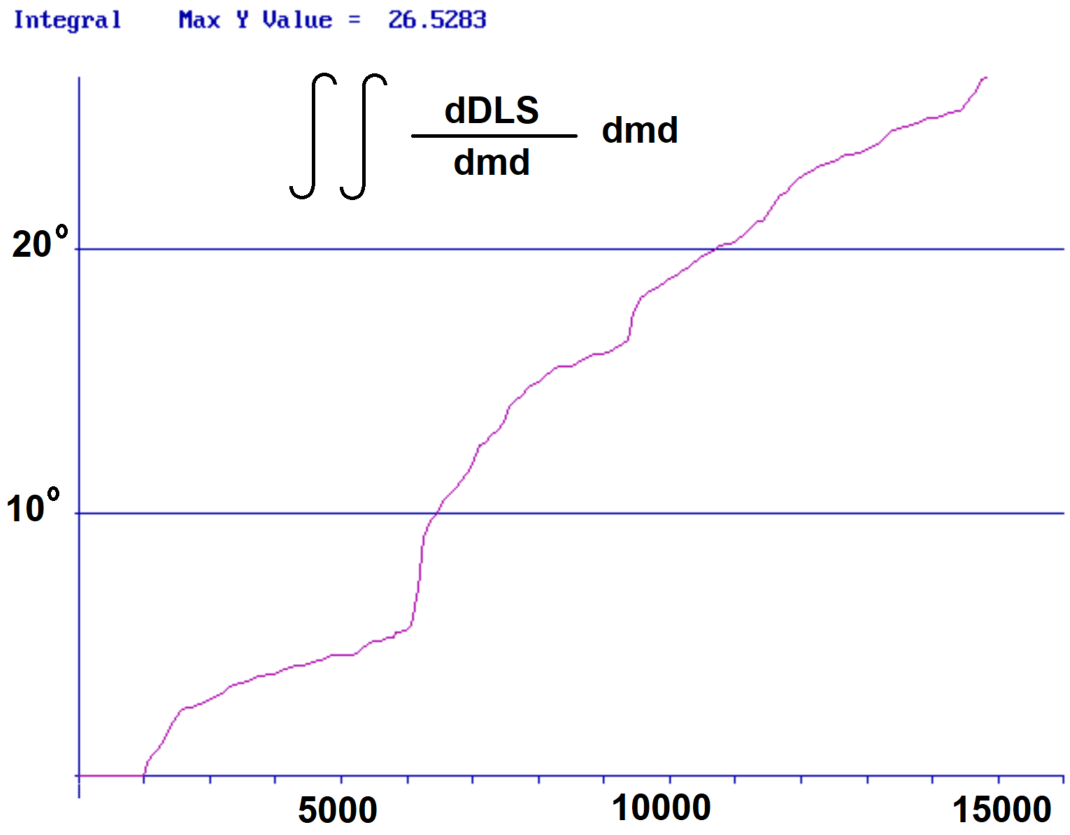
Differentiate the DLS curve dDLS/dmd

- Measures consistency
- Does not penalize planned curvature
- Only uses pulsed surveys
- May miss key points
- No simple comparison
- Hard to explain



Double Integrate the Differentiation

- Measures consistency
- Does not penalize planned curvature
- Provides ‘unwanted curvature’
- Only uses pulsed surveys
- May miss key points



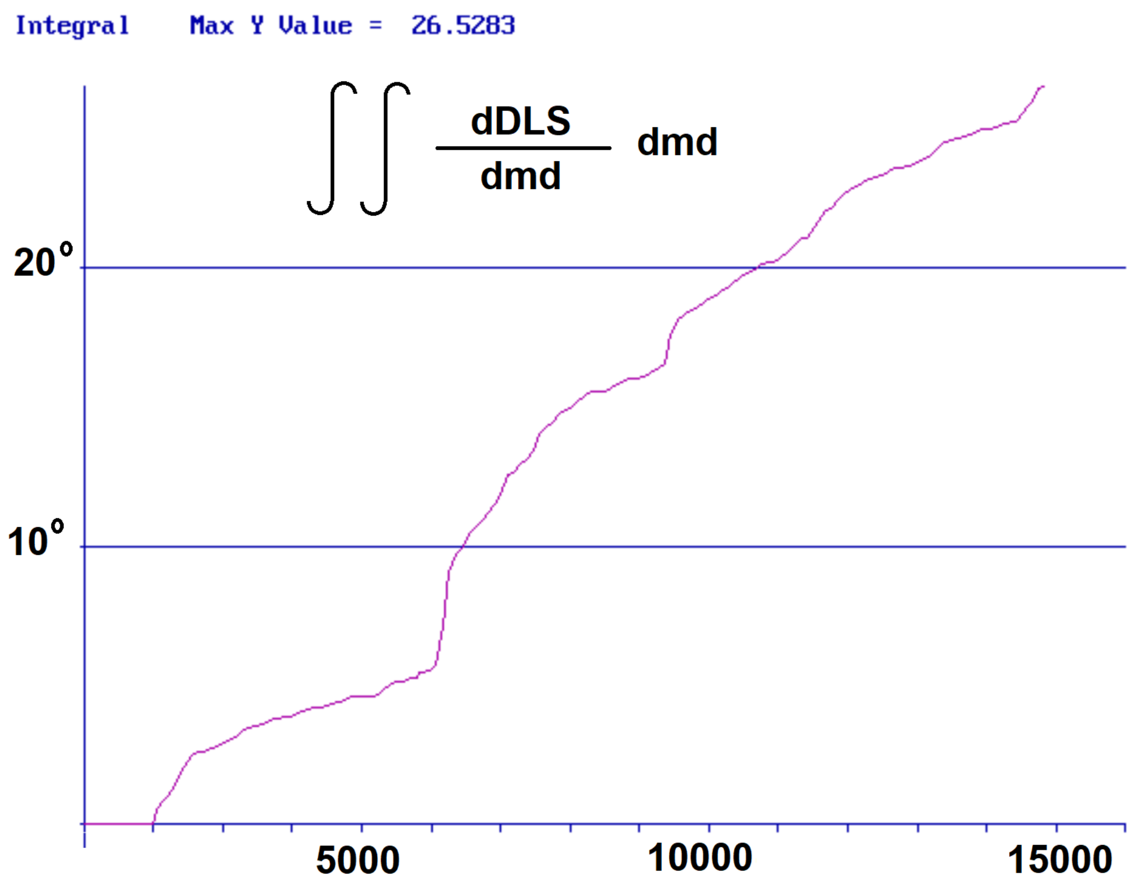
Tortuosity Index

TI =

Unwanted Curvature /

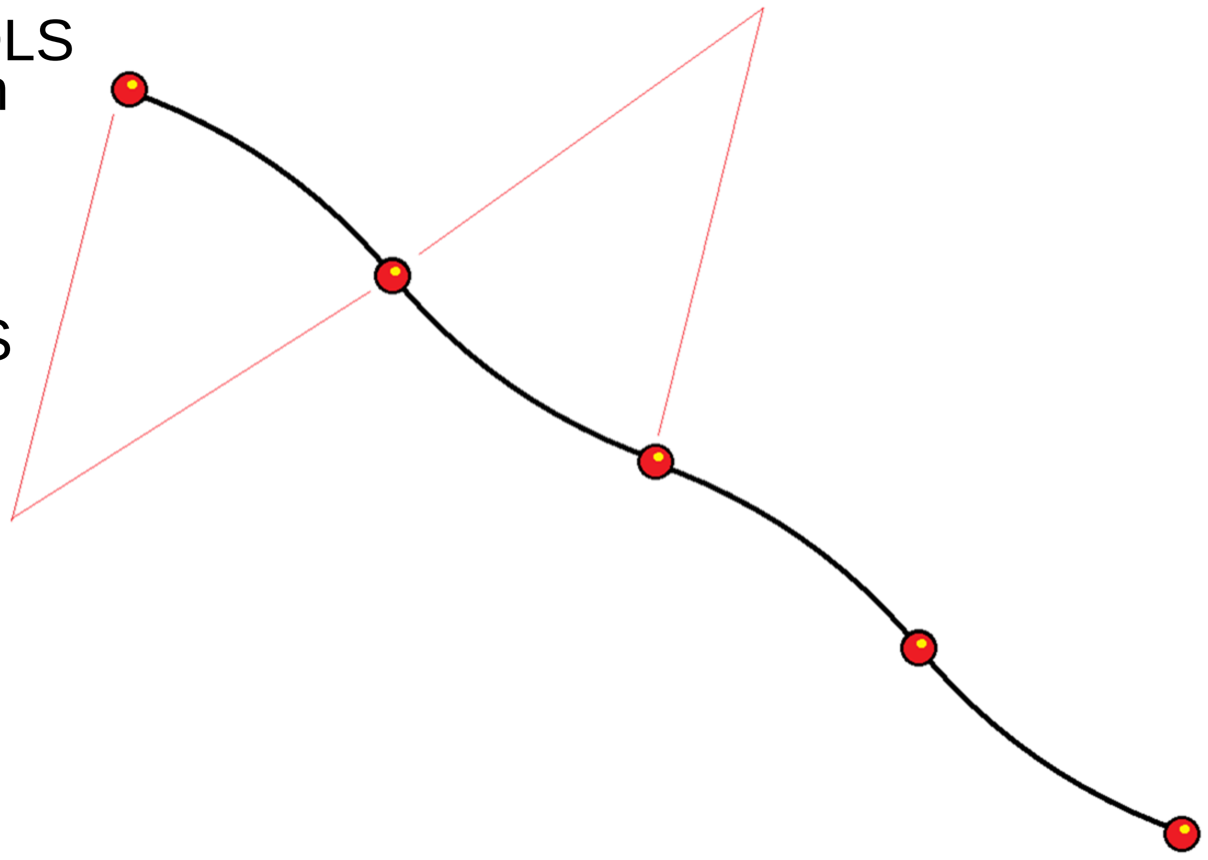
(Total Curvature – Unwanted Curvature)

(Akin to Unwanted / Planned)



A more revealing 3D approach

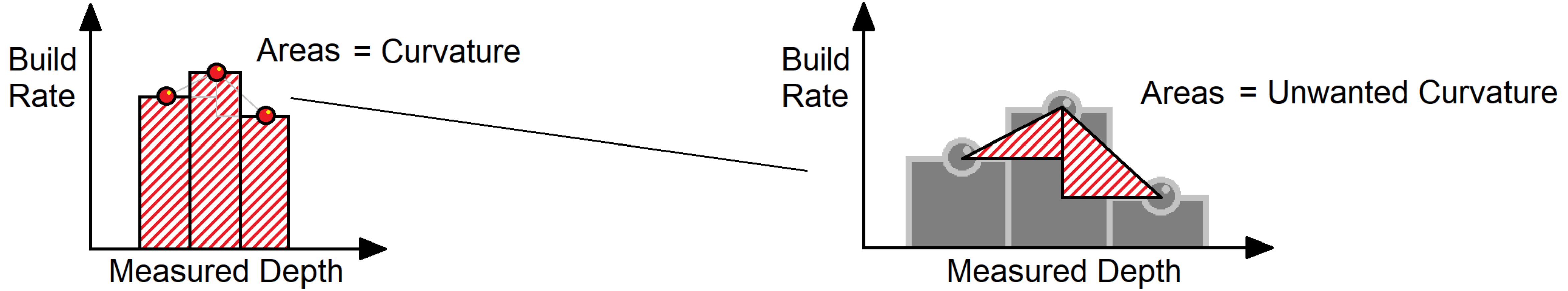
- A BHA designed to give a constant DLS may produce good consistency when 3D arcs are assessed for curvature.
- But what if one survey interval was a build followed by a drop?
- This would assess as consistent DLS from one survey to another
- SO …..
- Assess a Tortuosity index for build consistency and turn consistency separately
- Then combine to a single index



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)

Calculating High Side and Lateral Tortuosity (cont'd)



- Total Build = Sum (BR x δMd)
- Total ET = Sum (ETR * δMd)

- Unwanted build = .5 x δBR x δMd
- Unwanted ET = .5 x δETR x δMd

High Side Tort Index = Unwanted Build / (Total Build – Unwanted Build)

Lateral Tort Index = Unwanted ET/(Total ET – Unwanted ET)

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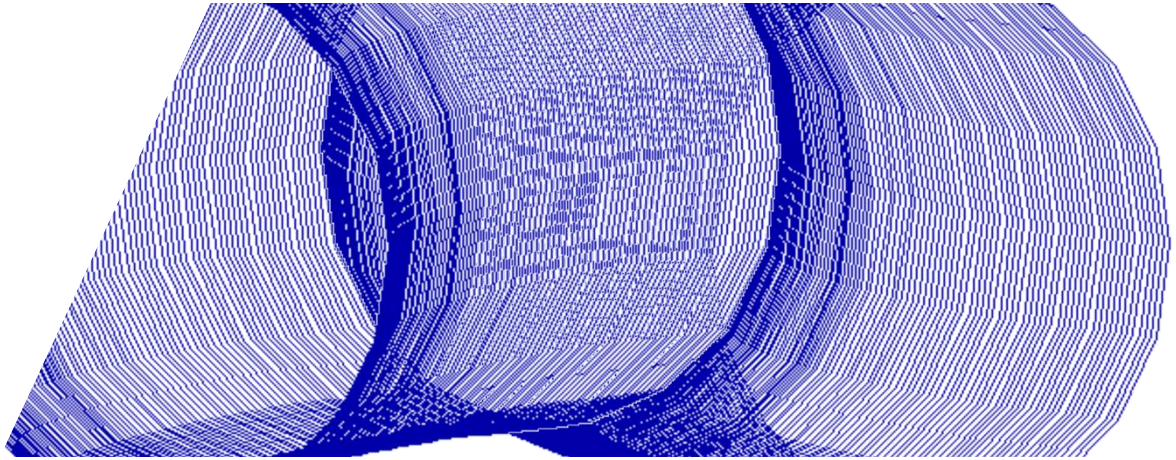
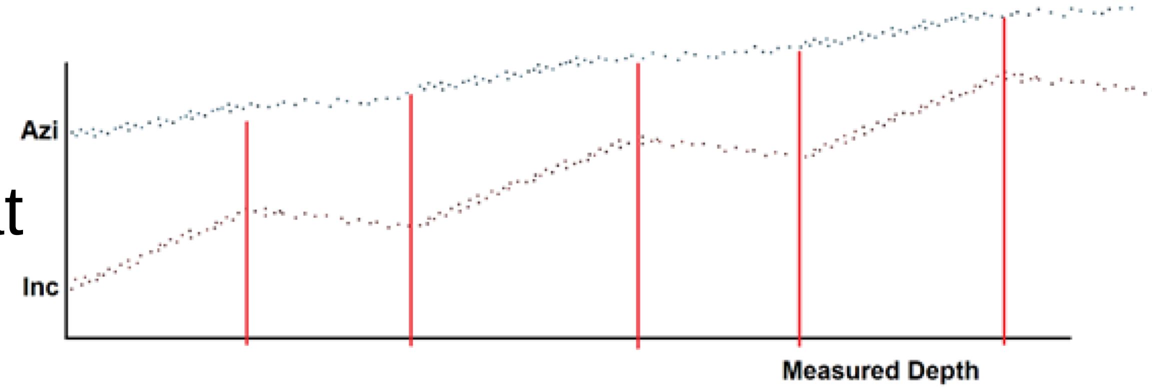
Measuring High Resolution Tortuosity

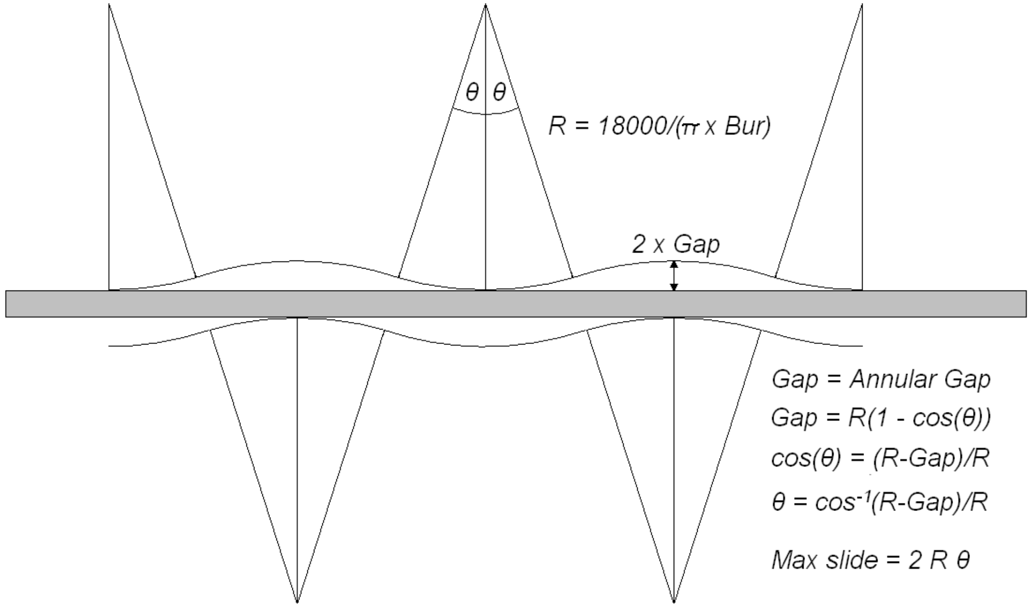
- Uses all available data
- Assesses true motor yield functions
- Models a true trajectory in 3D
- Does not miss key points
- Informs T&D and Hydraulics calcs
- Trains DDs or Automation to minimise tortuosity
- Allows proper assessment of impact at two thresholds





Tortuosity Thresholds

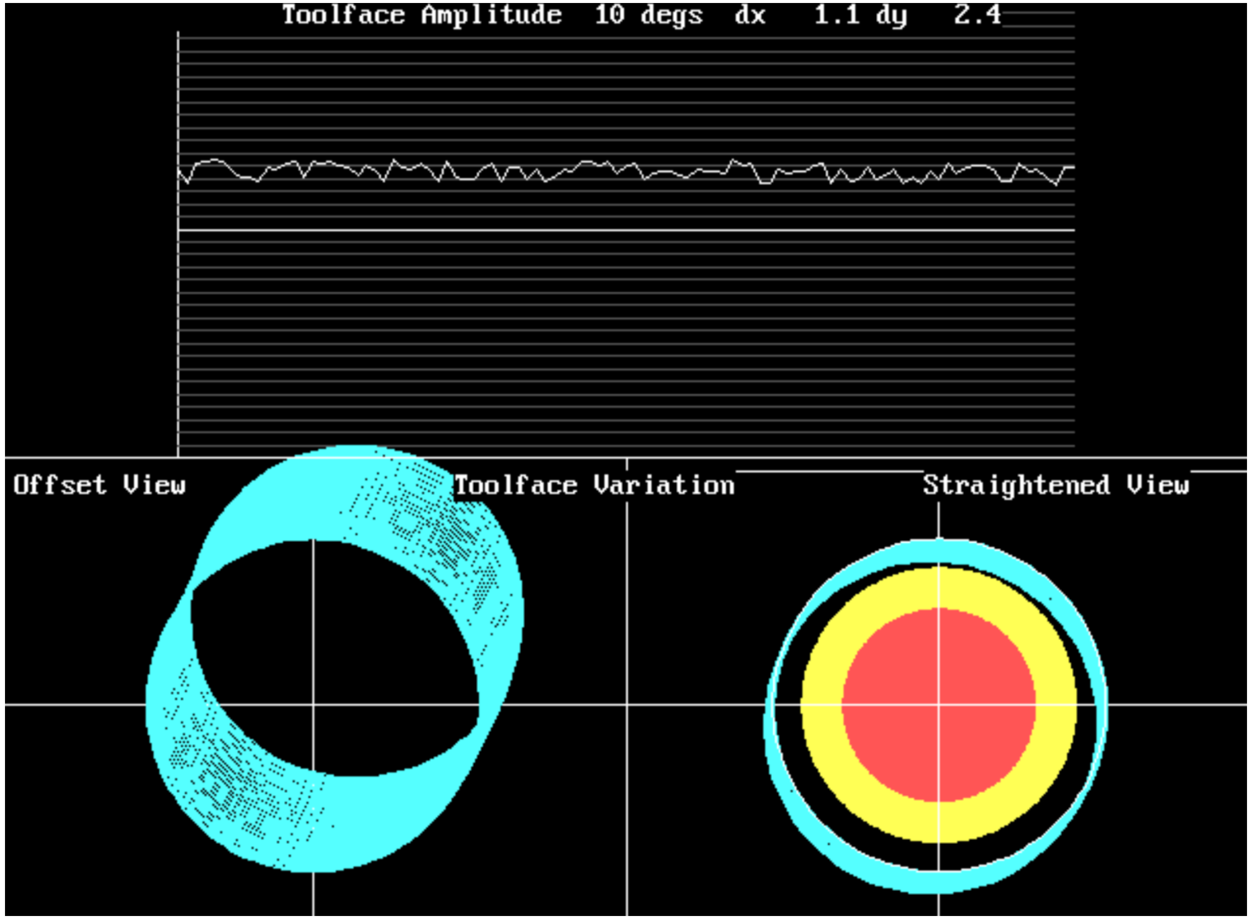
- Stressing Casing
- Stressing Drill Pipe



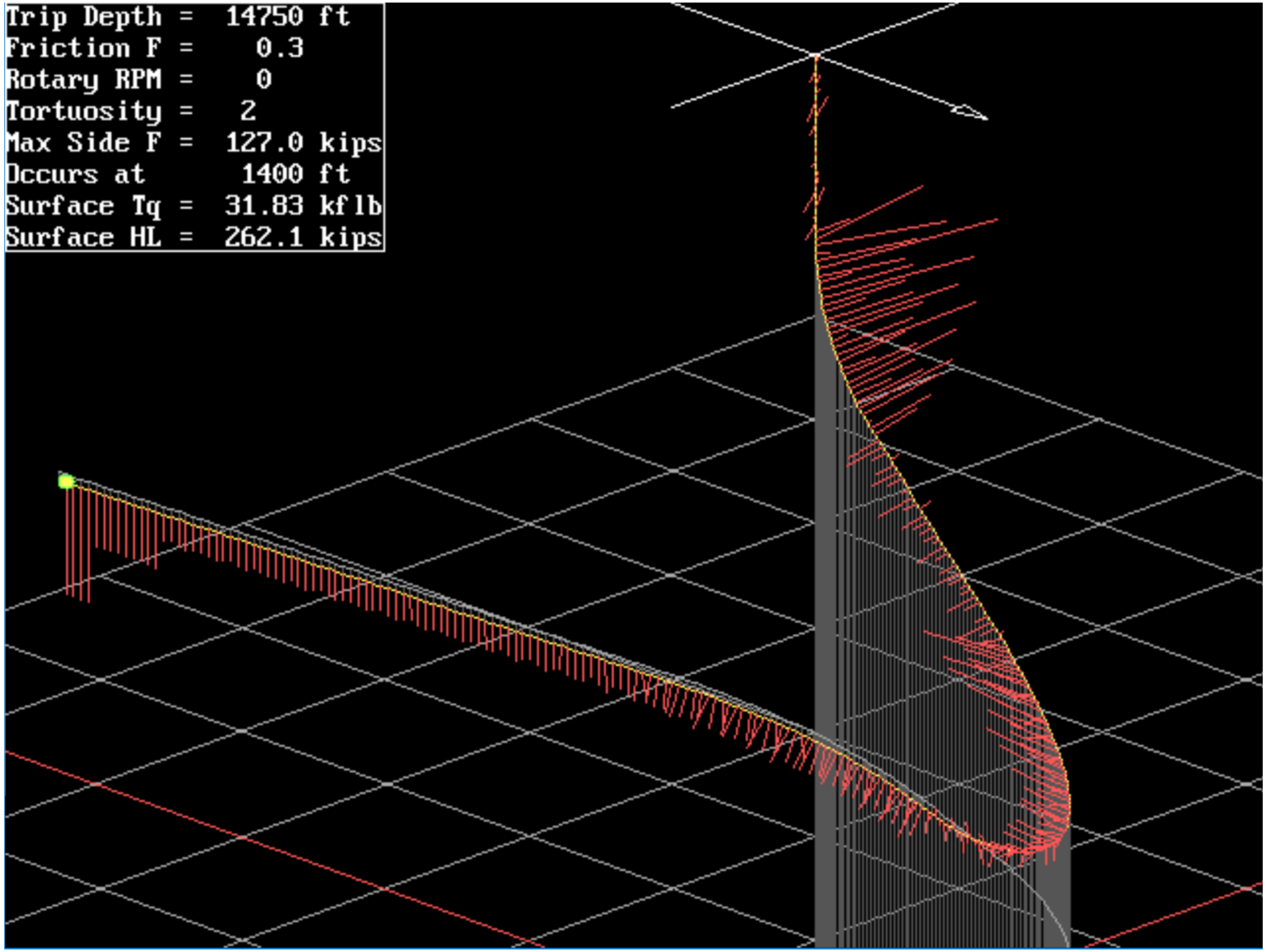
DLS °/100	13 3/8" 17 1/4	9.5/8" 12 1/4	7" 8.5
1	89 ft	71 ft	54 ft
2	63 ft	50 ft	38 ft
3	51 ft	41 ft	31 ft
4	44 ft	35 ft	27 ft
5	40 ft	32 ft	24 ft
6	36 ft	29 ft	22 ft
7	34 ft	27 ft	20 ft
8	31 ft	25 ft	19 ft
9	30 ft	24 ft	18 ft
10	28 ft	22 ft	17 ft
11	27 ft	21 ft	16 ft
12	26 ft	20 ft	15 ft
13	25 ft	20 ft	15 ft
14	24 ft	19 ft	14 ft
15	23 ft	18 ft	14 ft
16	22 ft	18 ft	13 ft
17	22 ft	17 ft	13 ft
18	21 ft	17 ft	13 ft
19	20 ft	16 ft	12 ft
20	20 ft	16 ft	12 ft

Two thresholds of acceptable tortuosity

- The amber area warns 'Encroaches on casing'
- The Red area warns 'Encroaches on drillpipe'
- This can be measured by modelling a tubular set in the wellbore and reporting stresses necessary to constrain within the hole.



Drag Side Forces Modeled Correctly



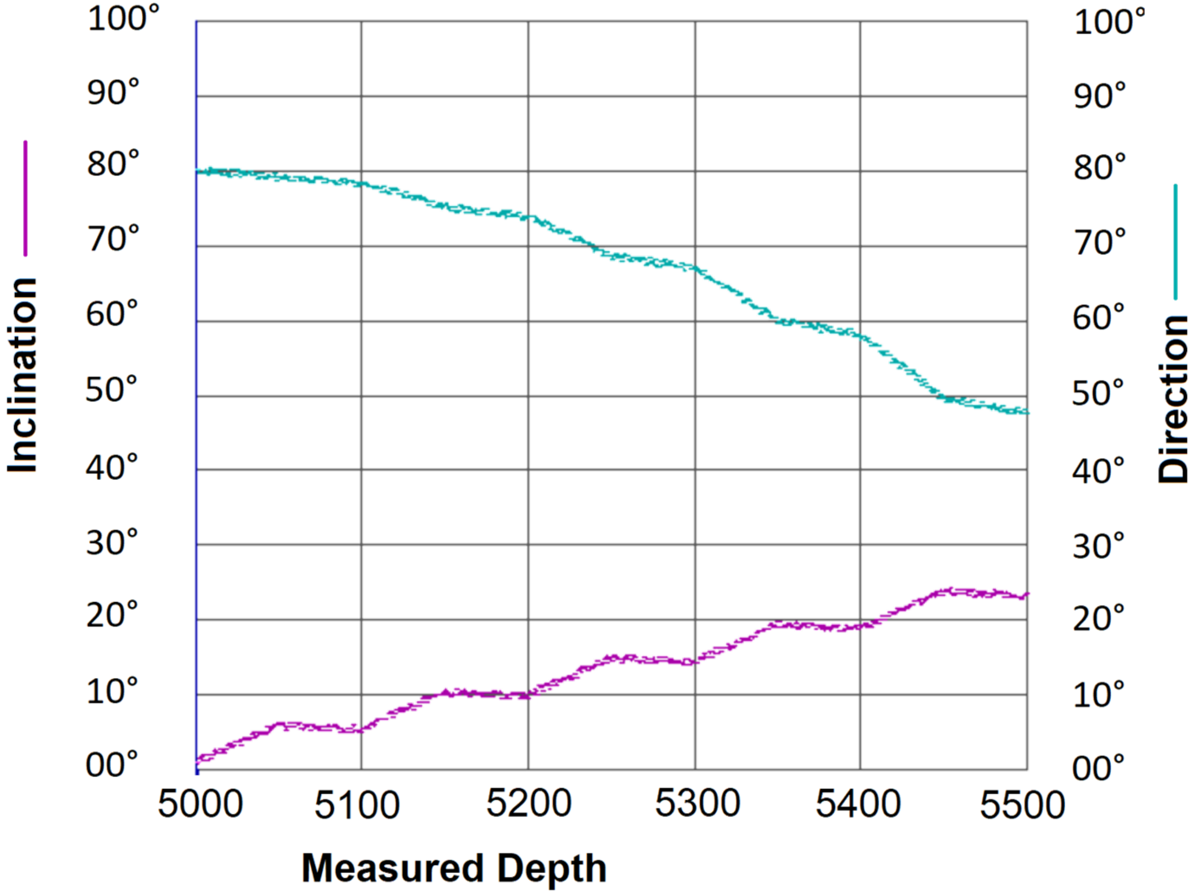
A simple approach

- Use the 3D Tortuosity Index for drilling performance on normal surveys with the caveat that:
  - ‘Normal’ TI values should be assessed for local scenarios
  - TI values should be assessed for different hole sections
- Normalise the high resolution sections by the Arc to Chord Threshold method.
  - Suggest a common standard of .5 inches
    - Ignores micro doglegs within the annular gap
    - Can be used with continuous data
    - More accurately indicates casing or completion risks

Tortuosity Applied to Continuous Data

- Observations << 10ft
- DLS exaggerated
- Noise looks like Tortuosity

Advance along surveys until The Arc to Chord Correction Exceeds ½ inch and repeat.



Tortuosity Applied to Continuous Data

Imagine two vectors tangential to the well

Vector 1	dN	$\mathrm{Sin}(I_1)\ \mathrm{Cos}(A_1)$
	dE	$\mathrm{Sin}(I_1)\ \mathrm{Sin}(A_1)$
	dV	$\mathrm{Cos}(I_1)$
Vector 2	dN	$\mathrm{Sin}(I_2)\ \mathrm{Cos}(A_2)$
	dE	$\mathrm{Sin}(I_2)\ \mathrm{Sin}(A_2)$
	dV	$\mathrm{Cos}(I_2)$

The angle between these vectors is the same as the angle subtended by the arc of length delta M

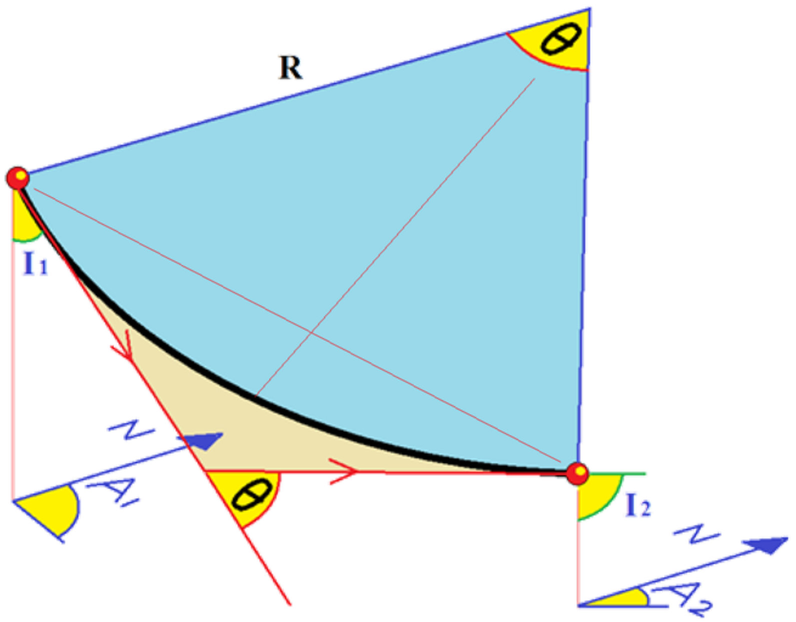
By the dot product rule the cos of this angle is

$$\cos(\theta) = (dN_1 \times dN_2 + dE_1 \times dE_2 + dV_1 \times dV_2)$$

so ......

$$\theta = \cos^{-1}(dN_1 \times dN_2 + dE_1 \times dE_2 + dV_1 \times dV_2)$$

and since $R\theta$ = delta M R = delta M / θ



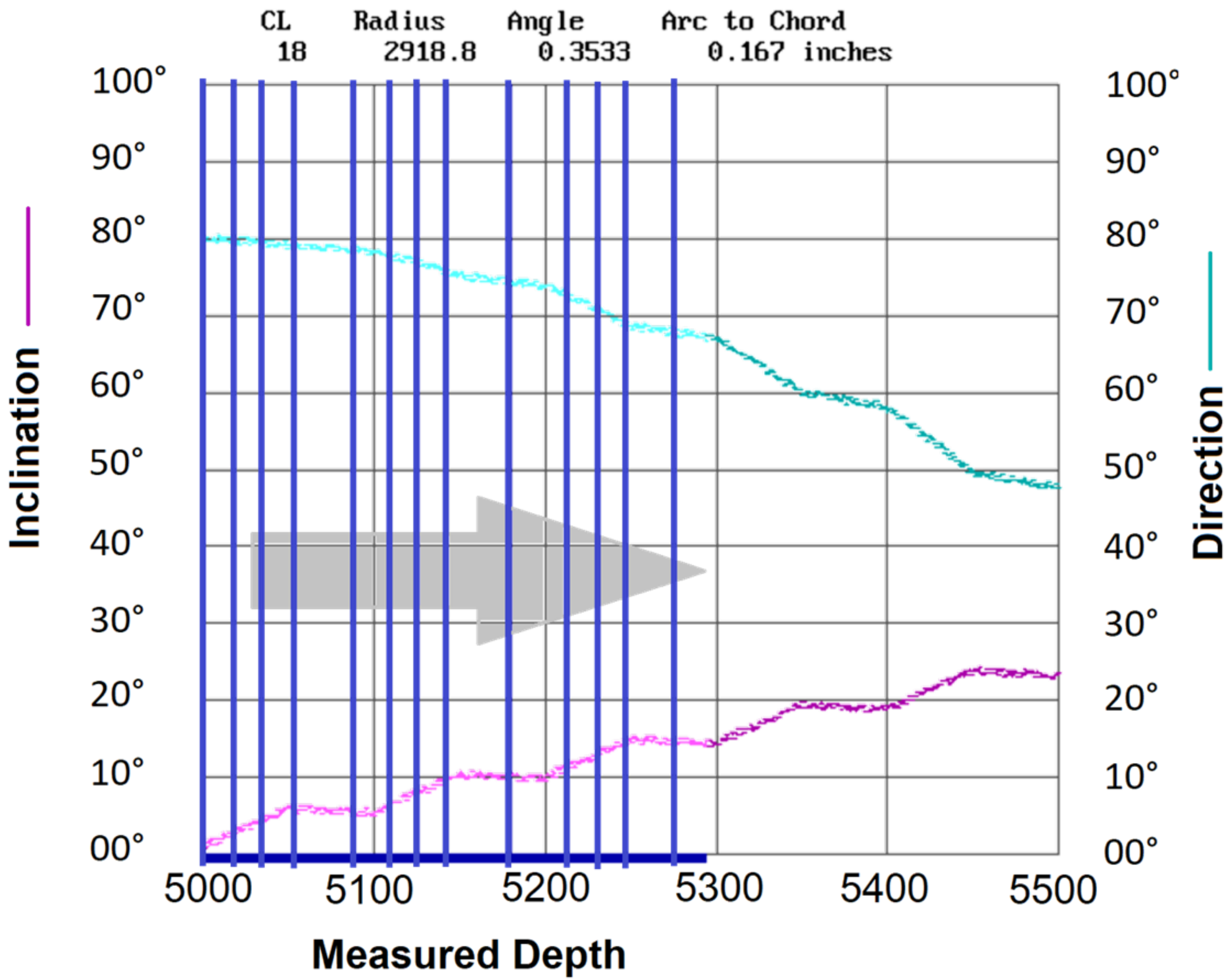
Arc to Chord Correction is just

R (1 - Cos (θ / 2))

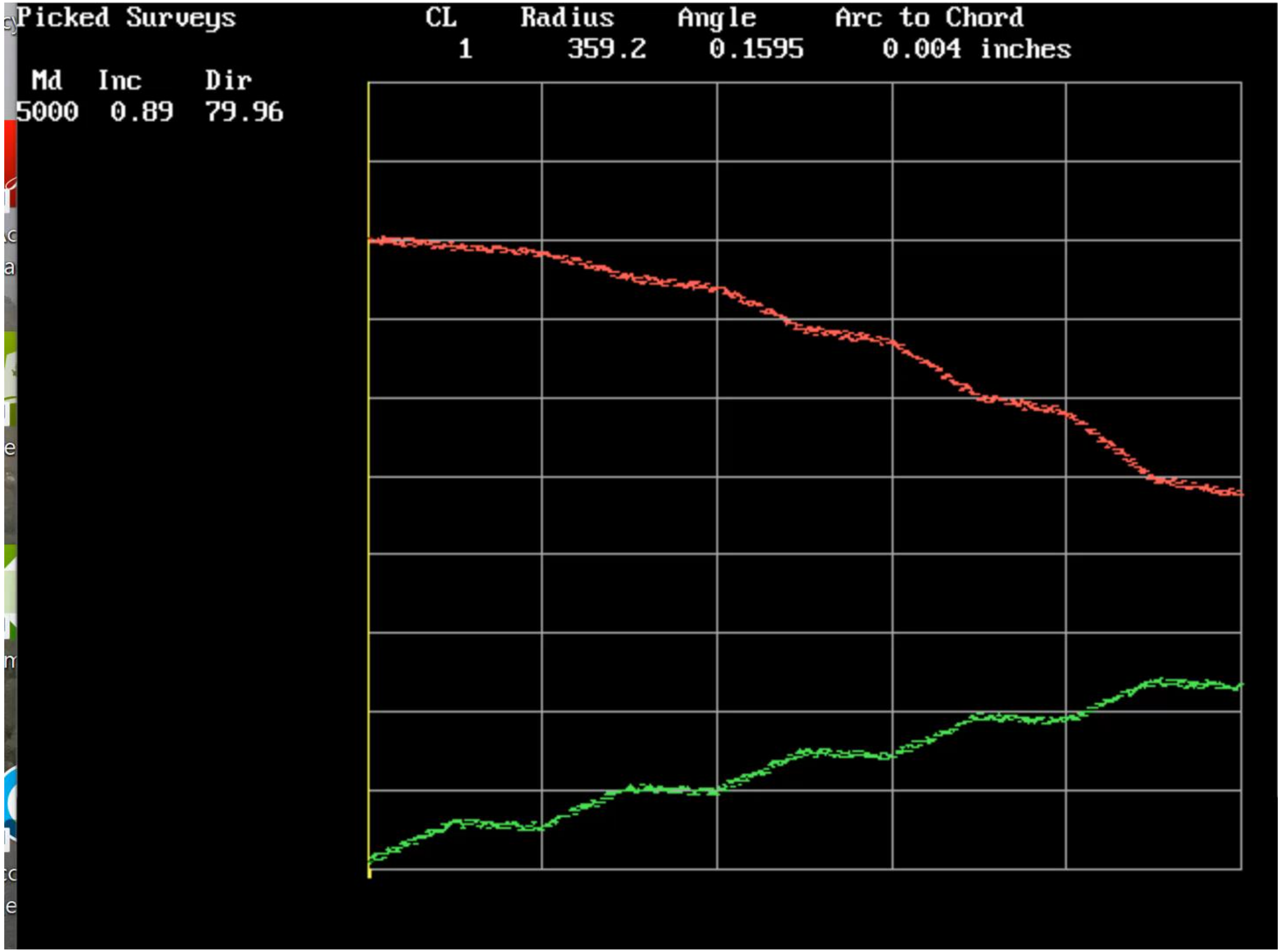
Only the picked surveys are then included for Tortuosity Analysis

Picked Surveys

Md	Inc	Dir
5000	0.89	79.96
5016	2.61	79.37
5033	4.71	79.45
5051	6.21	79.07
5086	5.09	78.67
5108	6.60	78.03
5125	8.20	76.42
5142	9.79	76.00
5179	10.51	74.48
5210	11.58	73.16
5229	13.32	70.66
5246	15.17	69.15
5275	14.20	67.35

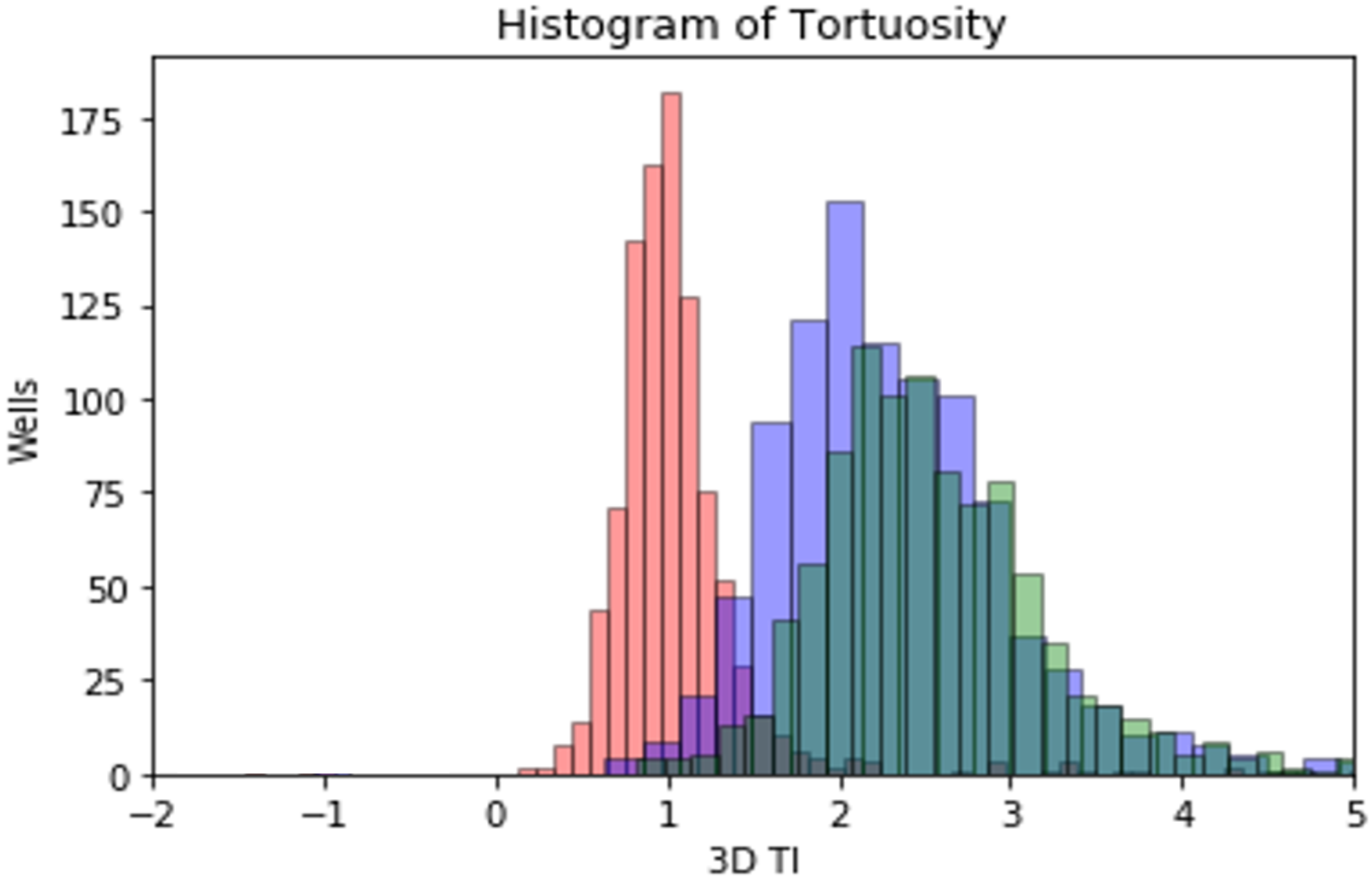


Automatic survey picks using the arc to chord correction filter



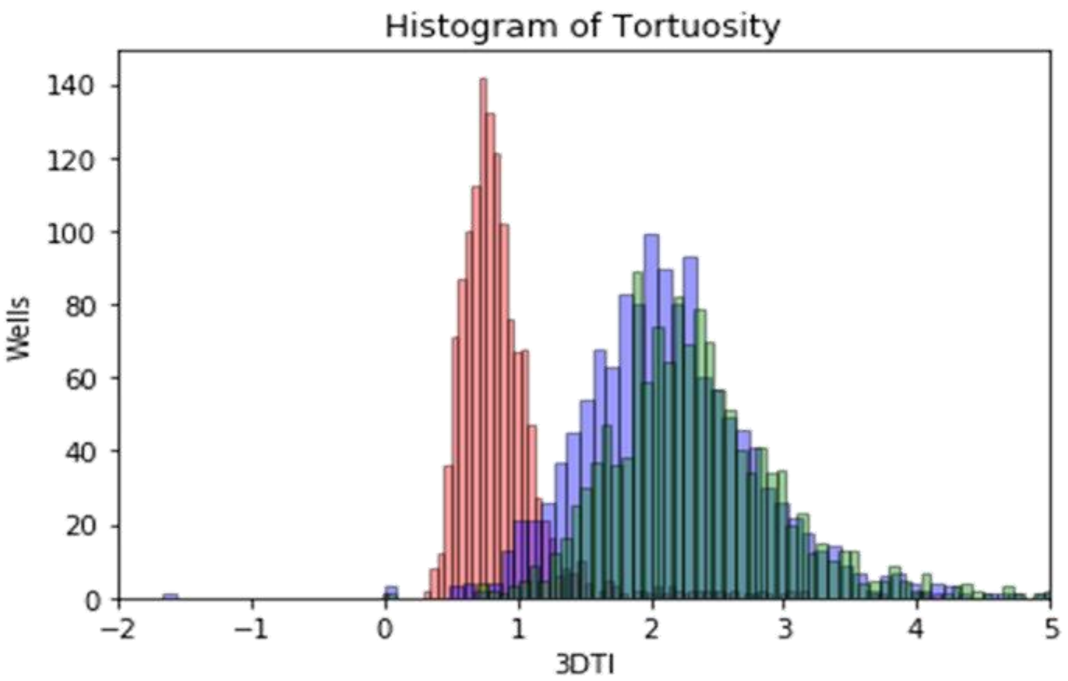
How does 3DTI work in practice?

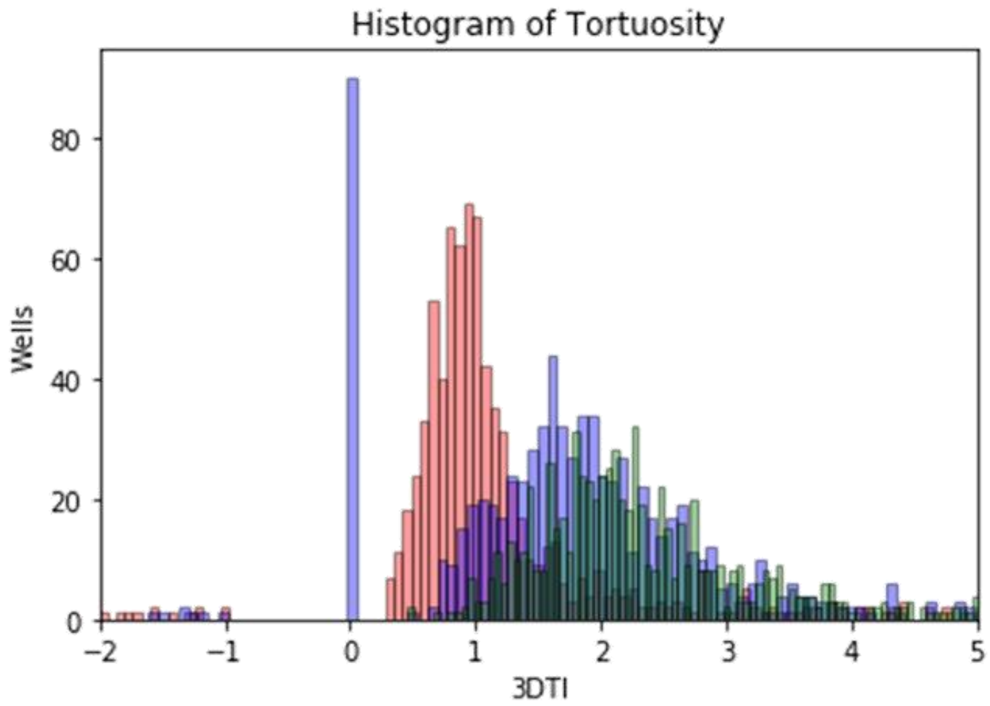
- 1400 wells study
- Various Operators
- Various depths
- Various Profiles
- Various locations



How does 3DTI work in practice?

Single Operator, Two separate business regions

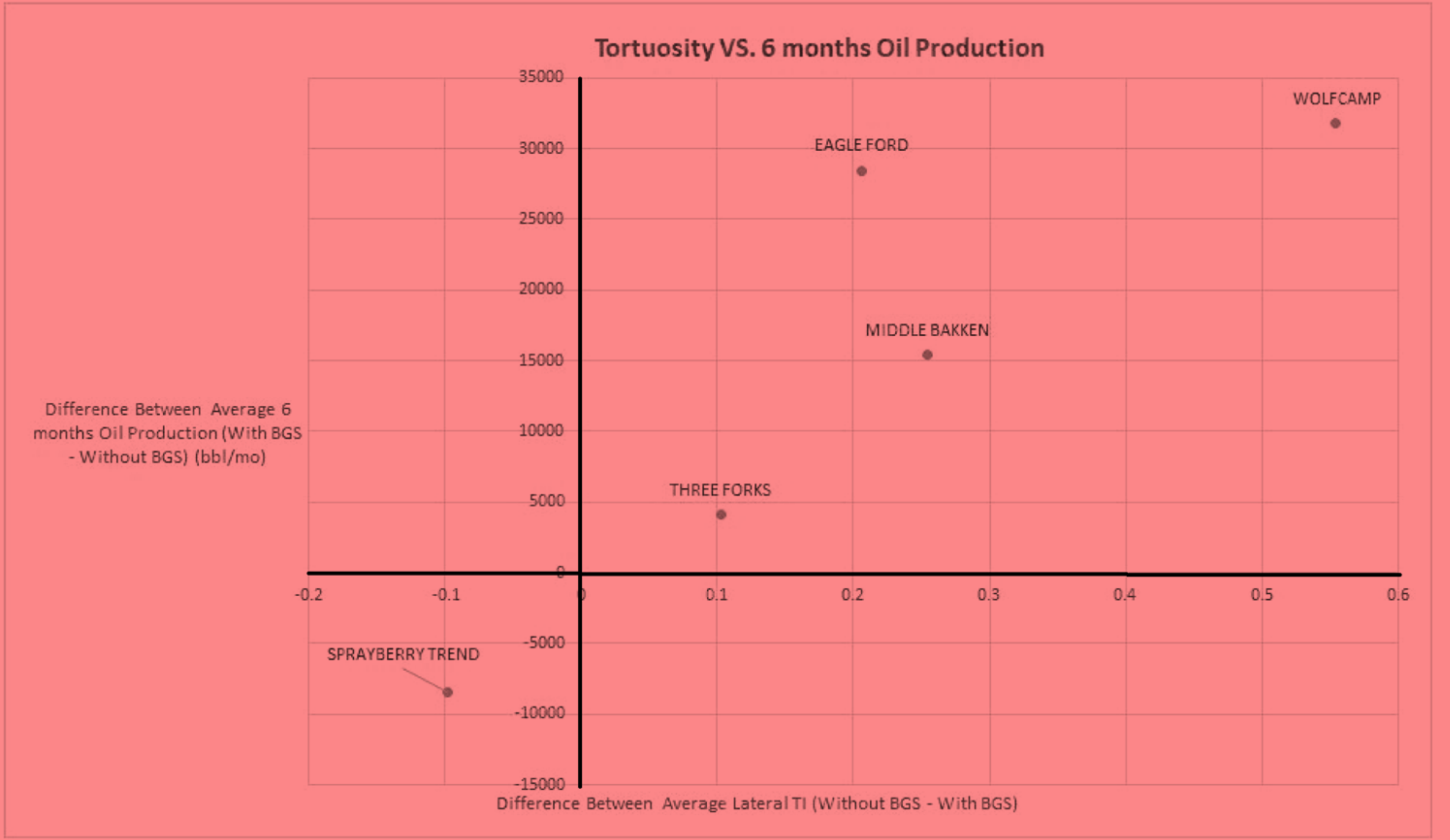




BGS Benefits Survey on Production

- Professor Mike Stafford
- Dylan Hills
- Guilherme Almeida
- Luke Moran
- Muhammad Alif Haidar

THE UNIVERSITY of TULSA



Plot 18: Tortuosity vs. First 6 Months of Oil production

Table 1: Tortuosity by Index by State

State	Classification	MTI 3D	Angus TI 3D	DDI
Texas	H&P	11.7	2.4	4.6
Texas	Offset	13.2	2.5	4.6
North Dakota	H&P	7.6	1.7	5.2
North Dakota	Offset	10.1	1.9	5.0

‘Normal’ varies from formation to formation

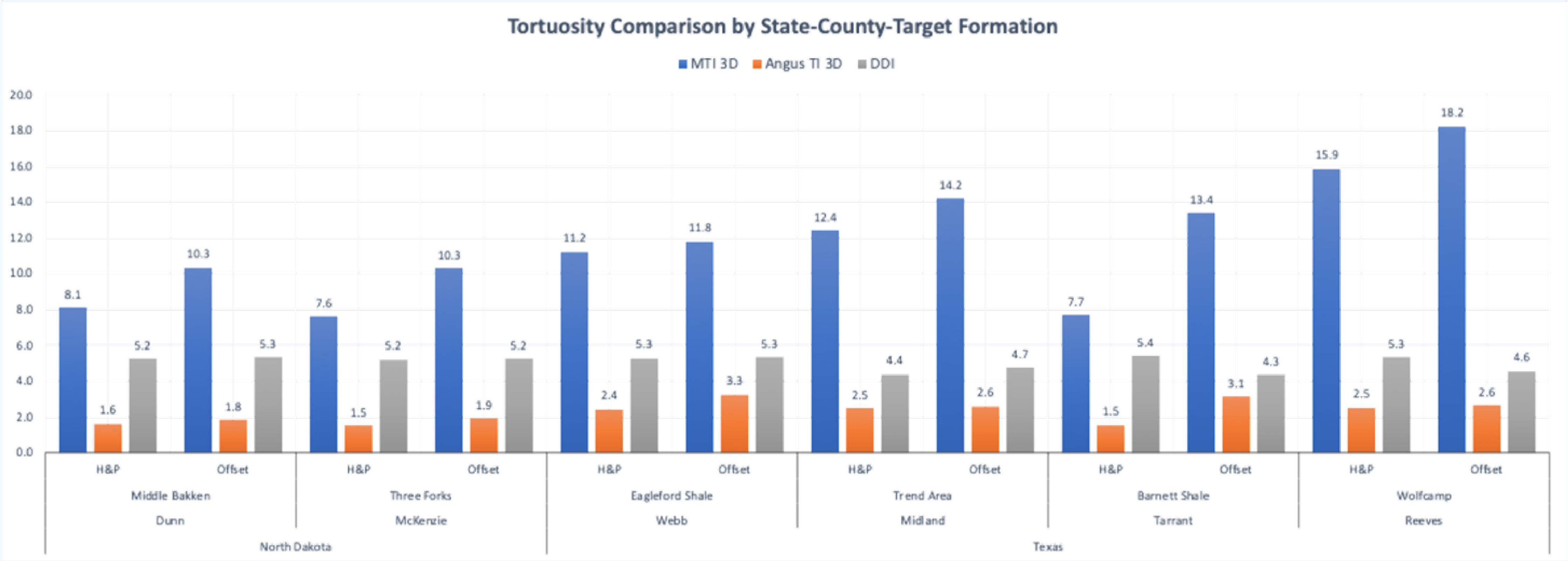


Figure 11: Tortuosity Comparison by State-County-Target Formation

Some evidence that Improved Tortuosity helps production

First 6 BOE Production vs Angus TI 3D (Lateral Section)
TX-Bartnett Shale Formation-1 Mile Lateral

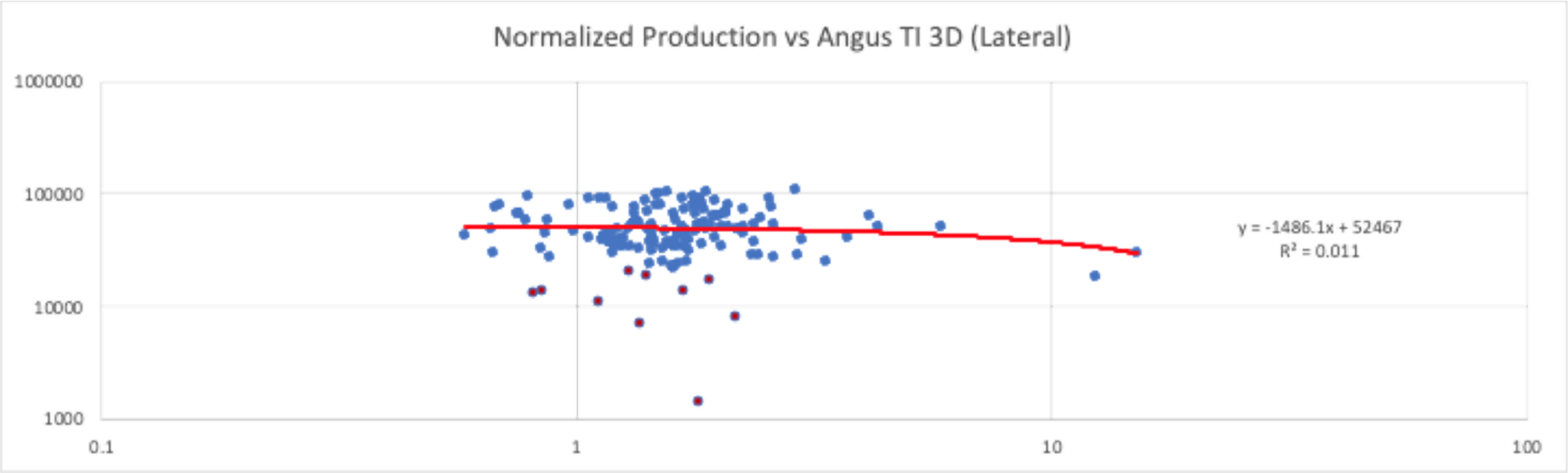


Figure 21: Normalized Production vs Angus TI 3D

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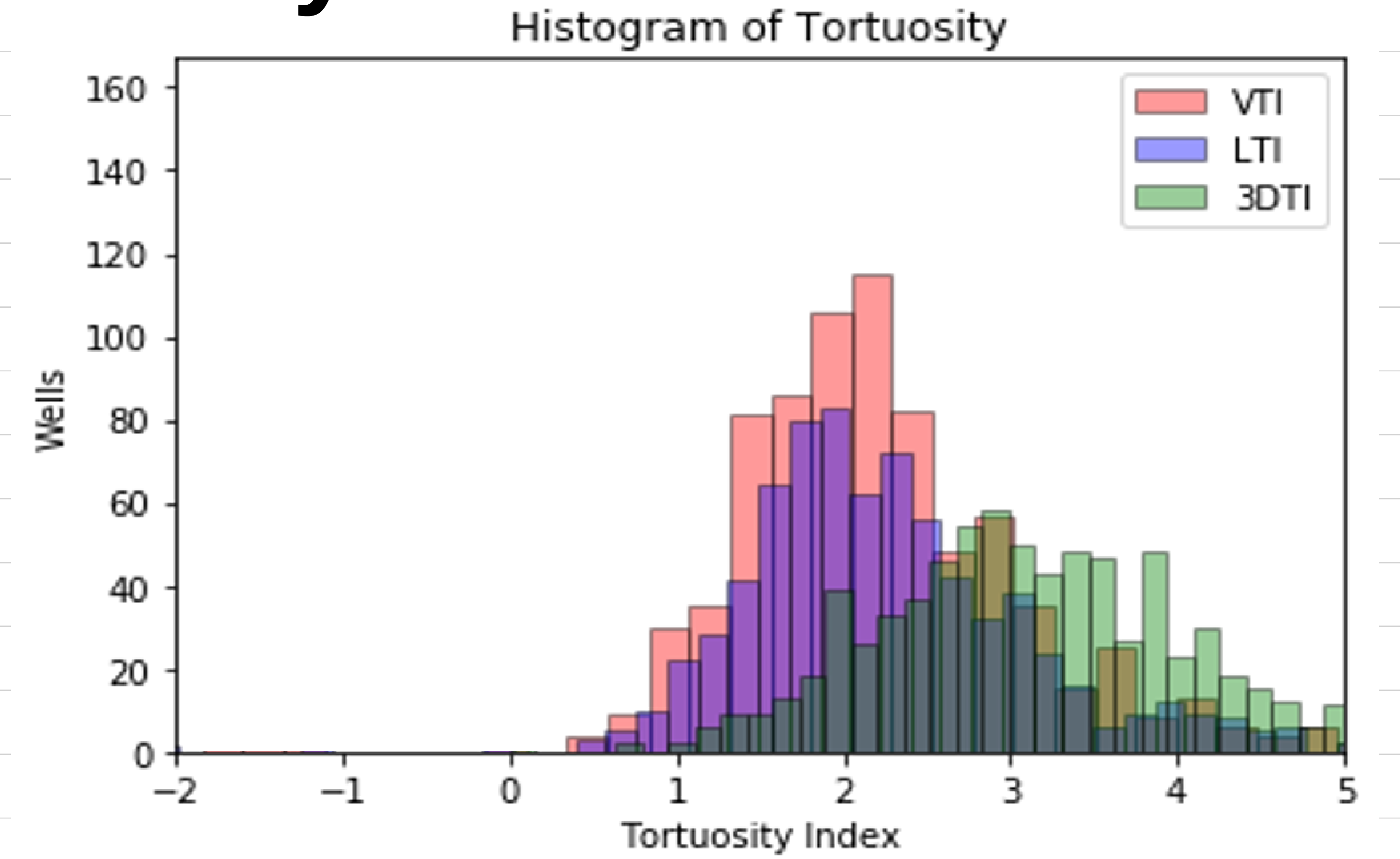
From 2000 well analysis

- In the Vertical
- Average 3
- Bad 5



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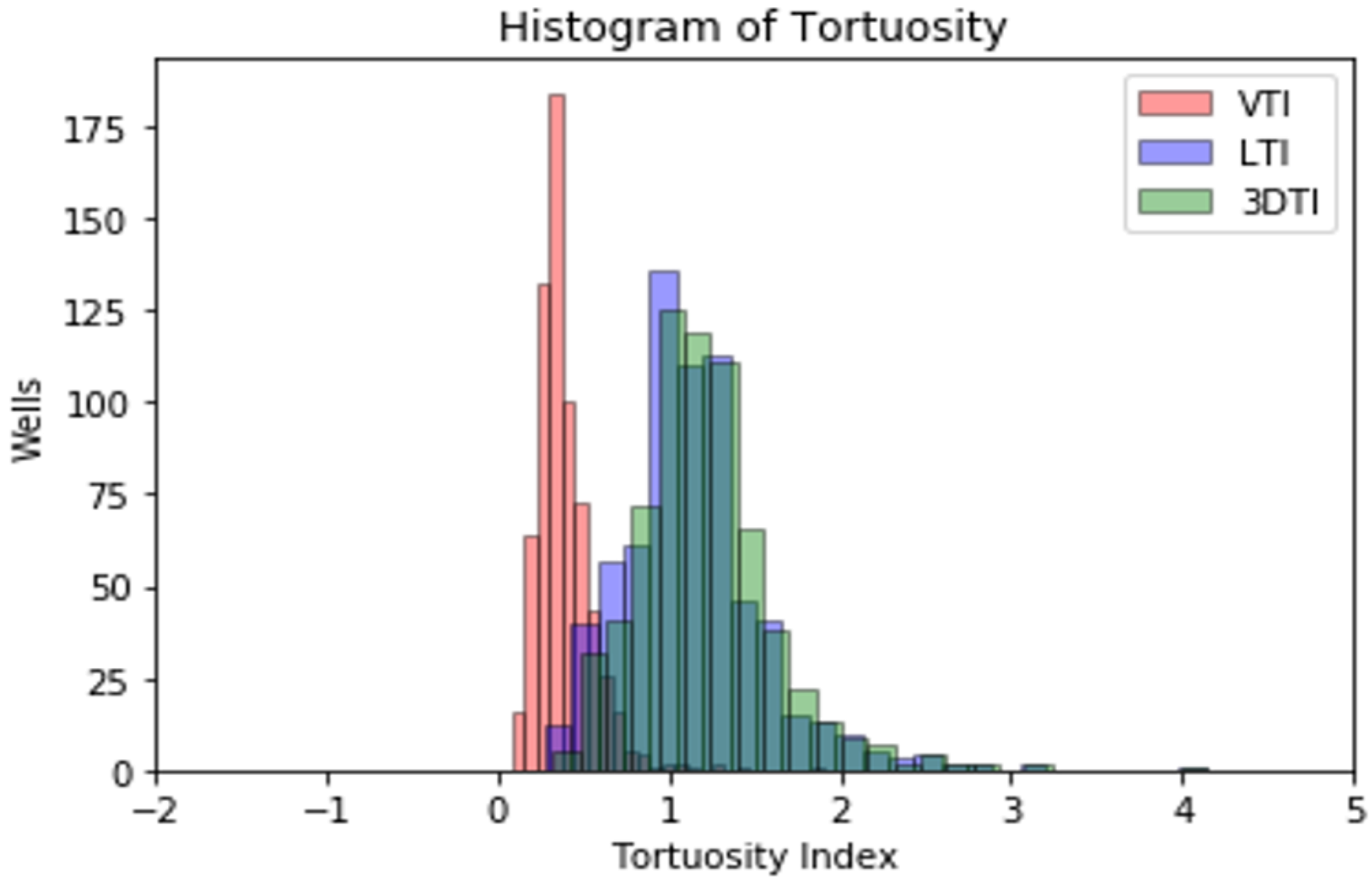
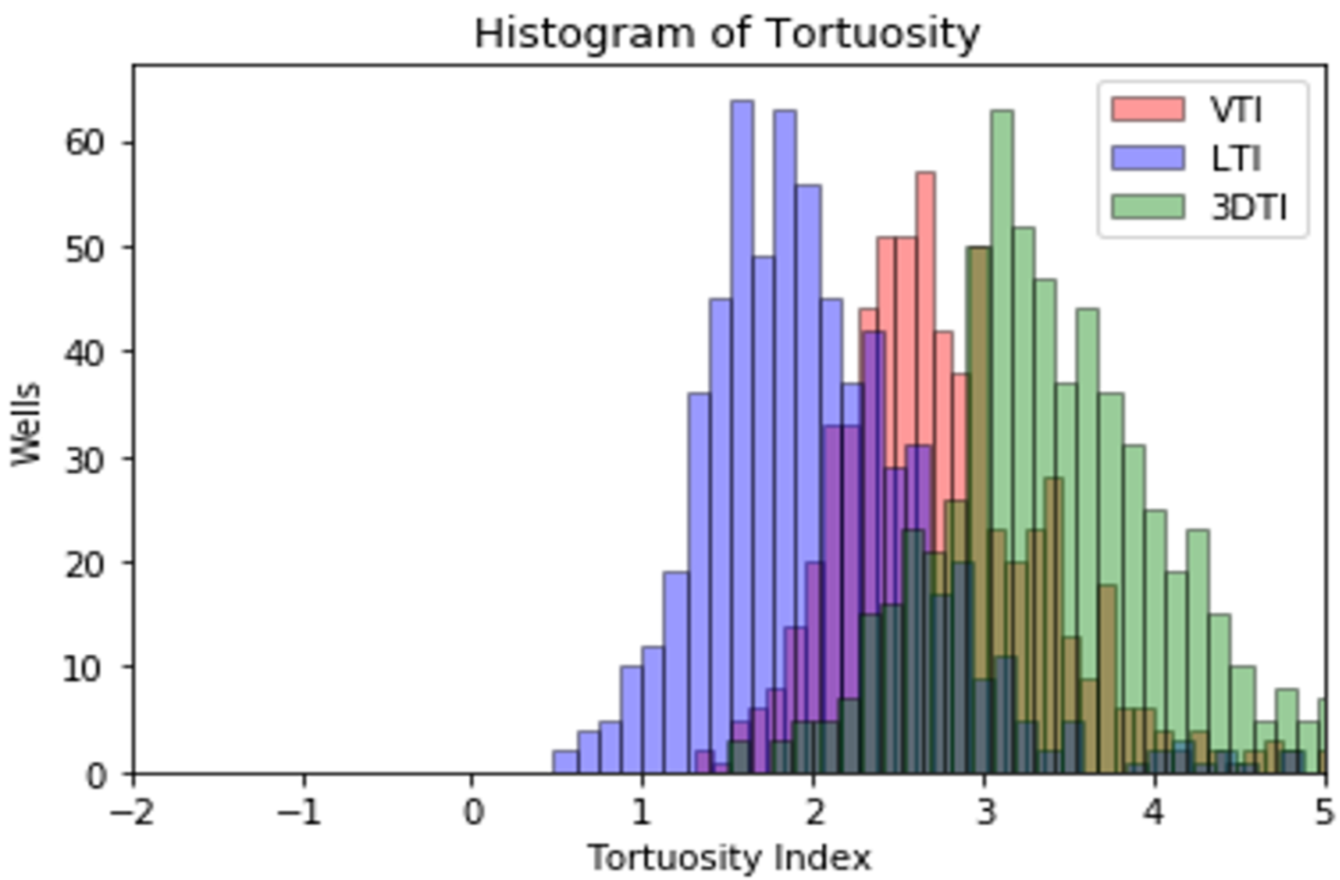
From 2000 well analysis

- In the Curve
- Average 1.5
- Bad 2.5



From 2000 well analysis

- In the Lateral
- Average 3
- Bad 5



Conclusions

- Tortuosity increases T&D and risk of tool or casing failure
- Tortuosity does not help production and may hinder
- 3D Tortuosity Indices are better than 2D
- The Jamieson formula is as good as any at identifying 3D Tortuosity
- A standard calculation would be helpful to the industry