Identification of Mechanical Stratigraphic Controls on IP30 (First Month) Hydrocarbon Production Volumes in the SCOOP (South Central Oklahoma Oil Province) Play, Oklahoma*

Carlos Molinares[1], Muizz Matemilola[1], Jing Zhang[1], Henry Galvis[1], Daniela Becerra[1], Lennon Infante[1], and Roger Slatt[1]

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Abstract

The SCOOP (South Central Oklahoma Oil Province) has been one of the most competitive lower 48 unconventional play areas in terms of persistent rig count. Oil and gas companies have significantly reduced operational costs and have become more efficient during drilling and completion activities. However, these efforts do not directly result in better horizontal well performance. Horizontal wells are also controlled by reservoir properties and the principal stress field orientation, which are sometimes not recognized before drilling.

To understand these reservoir controls, a detailed mapping and reservoir characterization study was conducted that included eight vertical wells, 12 horizontal wells and one cored Woodford Shale well. The horizontal wells were separated into two sets. The first set includes horizontal wells with the best hydrocarbon and liquid-rich production during the first month (IP30), which were drilled from north to south, with landing zones mainly associated with the upper part of the middle Woodford and the upper Woodford Shale. These rocks are characterized in outcrop by the presence of more brittle, silica-rich intervals, and characterized in core by higher Acoustic Impedance (A.I.), high Young Modulus (E) and low Poisson's ratio (ν) values. The second set of horizontal wells was poor in hydrocarbon liquid production. These wells were drilled from south to north and landed in more ductile lower Woodford Shale rock intervals. These two sets of wells were drilled by the same operator, under similar completion conditions and separated by a relatively short distance (< 1,000 ft).

The interaction of the principal stresses with the landing orientation of the horizontal wells was another factor analyzed in this study. In the SCOOP play, companies have demonstrated a preference for drilling horizontal wells in a north-south or south-north orientation, possibly because it is the fastest (economic) and most efficient way of infilling a section (640 acres) with a minimum number of horizontal wells. Due to the horizontal wells and the stress field orientation (SHmax ~ N85°±5°E), induced fractures are propagated vertically into some Mississippian pay units identified in the vertical wells analyzed. These could be stimulated during the completions and improve the hydrocarbon production in wells that land in the upper part of the middle Woodford and the upper Woodford Shale.

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Woodford Shale Consortium
Institute of Reservoir Characterization
http://irc.oucreate.com/

Outline

- *Overview*

Production statistics for Woodford horizontals

- *First-Month (IP30) Volumes of Grady County Well*

Approach to evaluating geologic factors affecting performance

- *Production Case Study*

Fracture characterization from outcrops

- *I-35 Outcrop Fracture Characterization*

Anisotropy from outcrops to subsurface

Anisotropy in the Woodford Shale

Anisotropy, subsurface mechanical stratigraphy, and microseismic

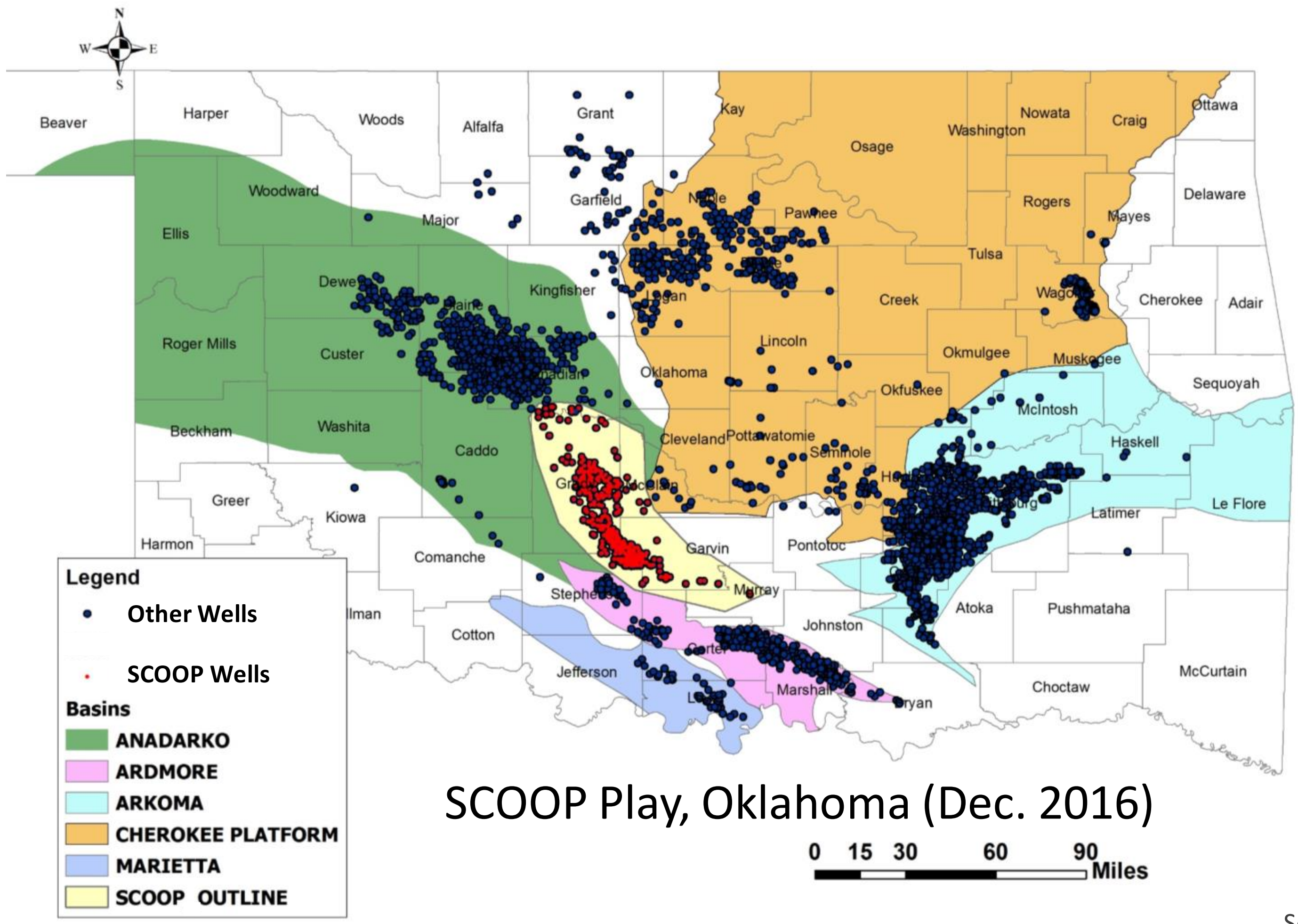
- *Woodford Shale Mechanical Stratigraphy*

Applications to Woodford drilling

- *Conclusions and Future Work*

Overview

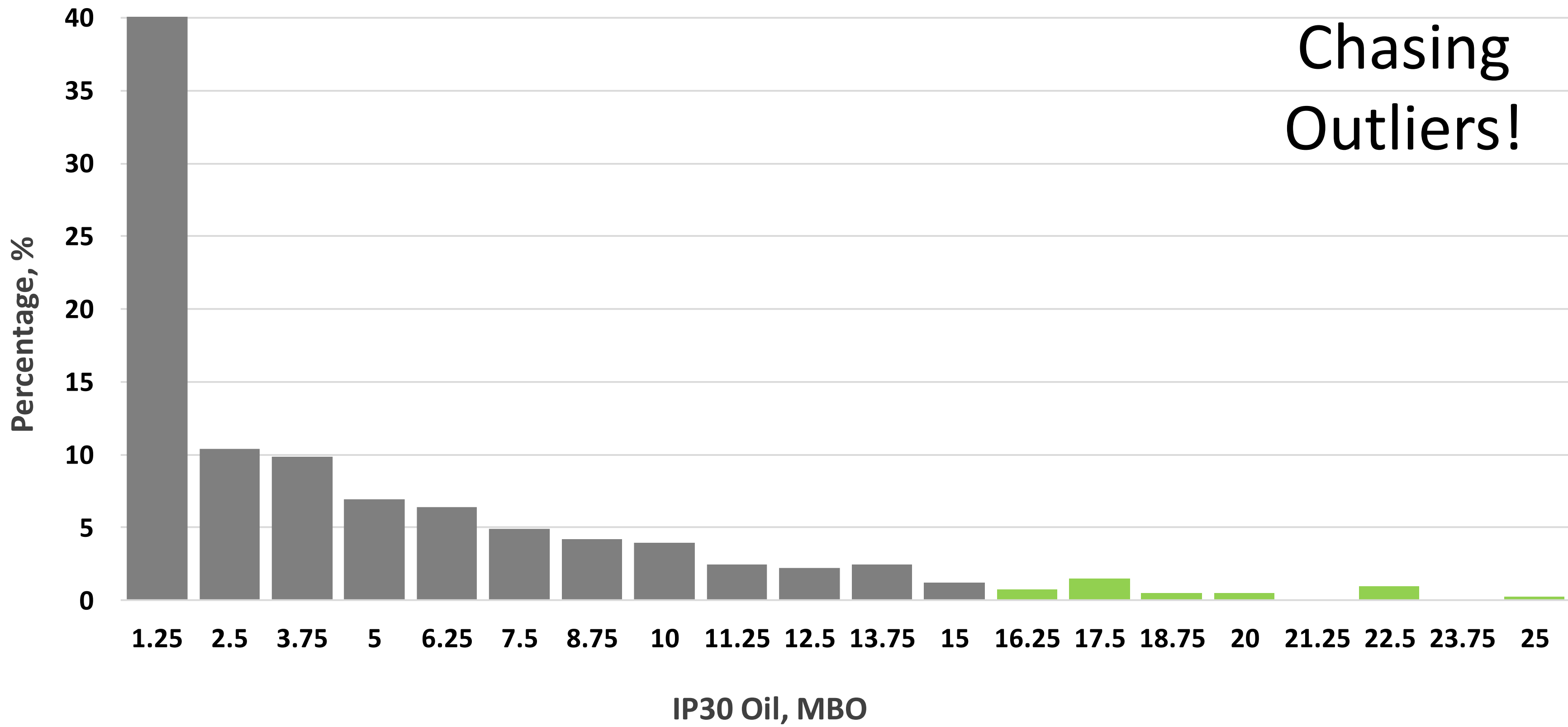
405 Horizontal wells from Garvin, Grady, McClain, Murray, and Stephens Counties



SCOOP Play, Oklahoma (Dec. 2016)

Sources: IHS & OCC

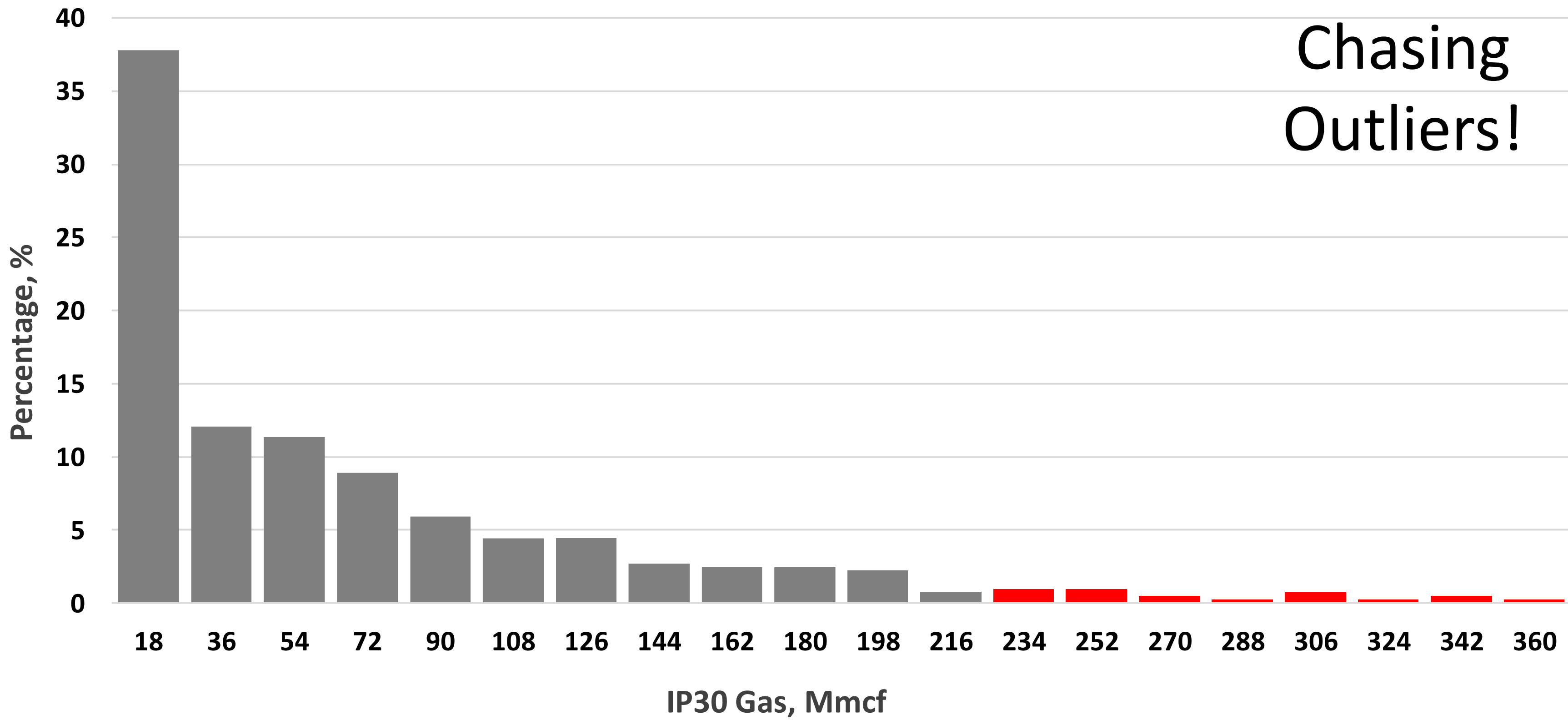
IP30 Oil Frequency Distribution



18 horizontal wells out of 405 produce more than 15 MBO within the first month (IP30) and represent 20% of first month oil volumes in the SCOOP

Sources: IHS & OCC

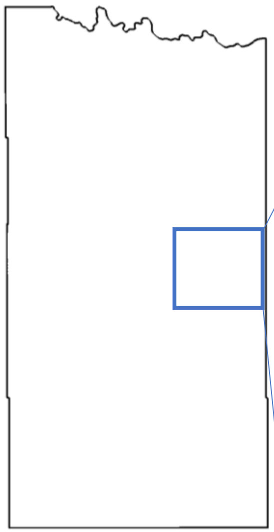
IP30 Gas Frequency Distribution

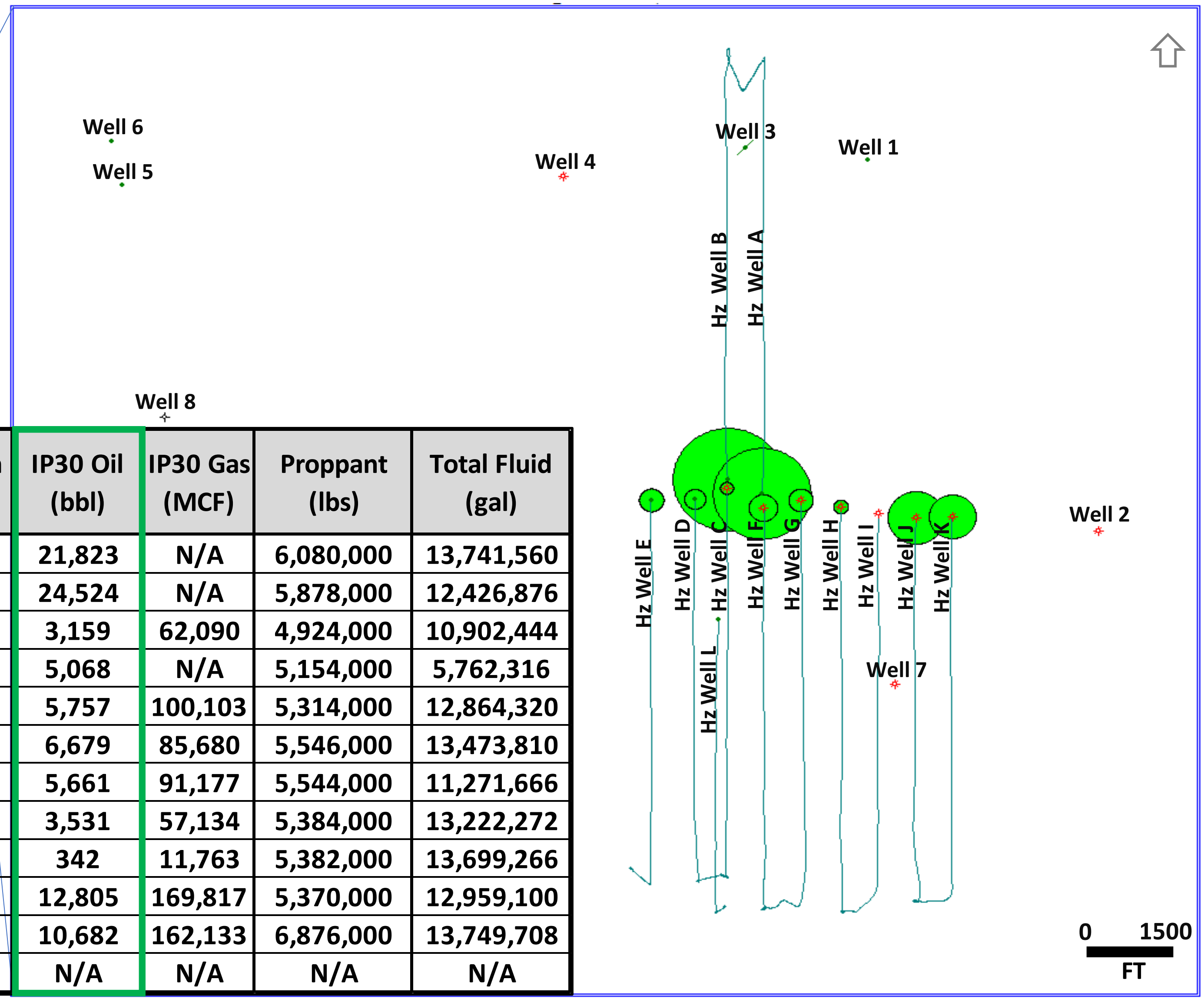


21 horizontal wells out of 405 produce more than 200 Mmcf within the first month (IP30) and represent 22% of first month gas volumes in the SCOOP

Sources: IHS & OCC

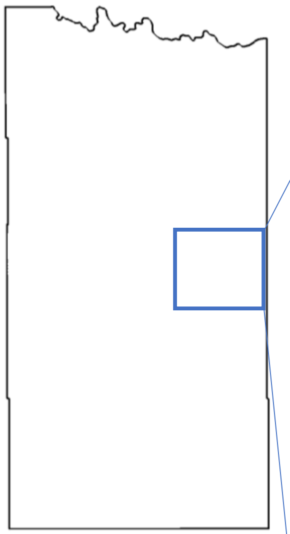
First Month (IP30) Oil Volumes

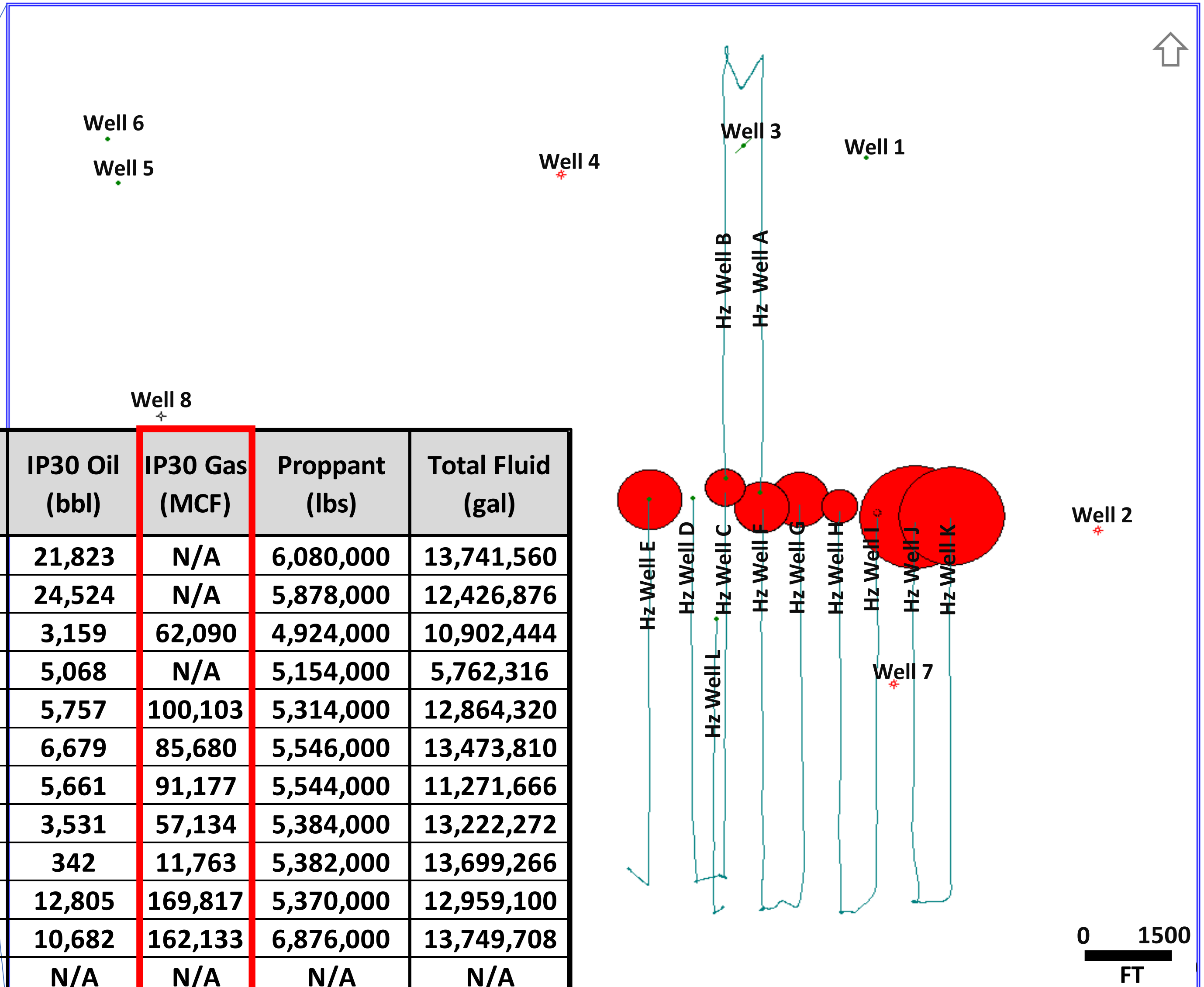




Well	Lateral Length (ft)	IP30 Oil (bbl)	IP30 Gas (MCF)	Proppant (lbs)	Total Fluid (gal)
A	7,839	21,823	N/A	6,080,000	13,741,560
B	7,555	24,524	N/A	5,878,000	12,426,876
C	7,514	3,159	62,090	4,924,000	10,902,444
D	7,293	5,068	N/A	5,154,000	5,762,316
E	7,149	5,757	100,103	5,314,000	12,864,320
F	7,753	6,679	85,680	5,546,000	13,473,810
G	7,912	5,661	91,177	5,544,000	11,271,666
H	7,853	3,531	57,134	5,384,000	13,222,272
I	7,743	342	11,763	5,382,000	13,699,266
J	7,439	12,805	169,817	5,370,000	12,959,100
K	7,493	10,682	162,133	6,876,000	13,749,708
L	N/A	N/A	N/A	N/A	N/A

First Month (IP30) Gas Volumes





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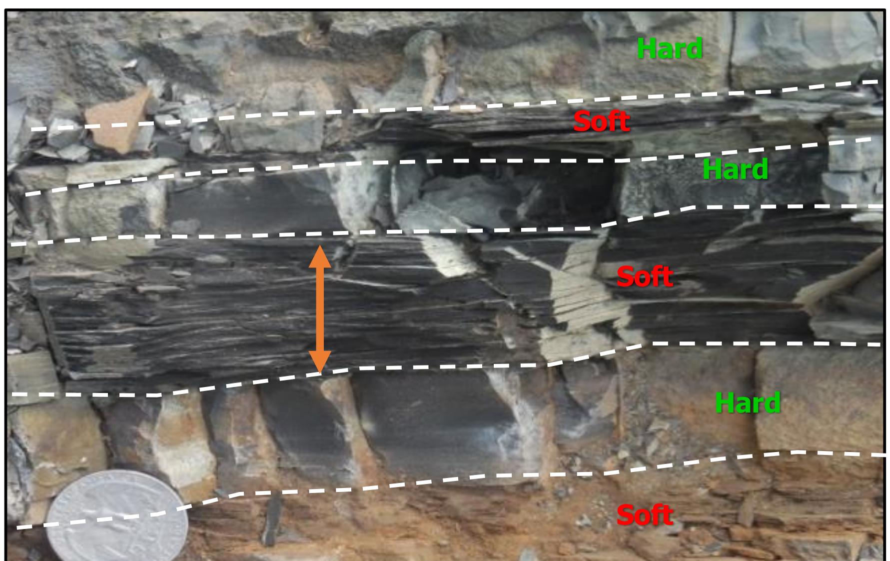
L	N/A	N/A	N/A	N/A	N/A

I-35 Outcrop: Measurements

Length: 305 meters



Measurements at 0.5ft increments

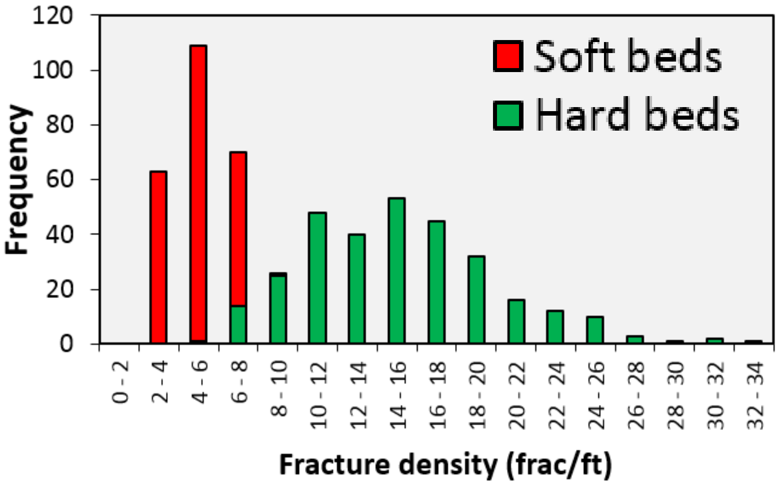
"Hard" = Chert

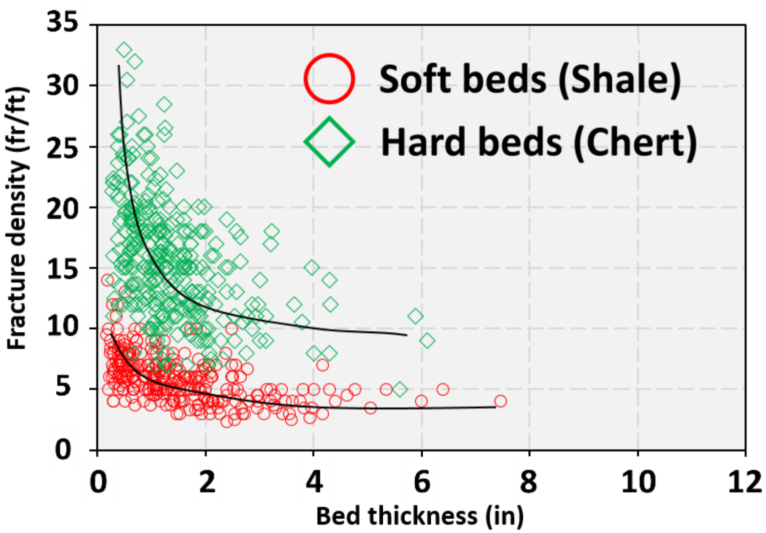
"Soft" = Shale

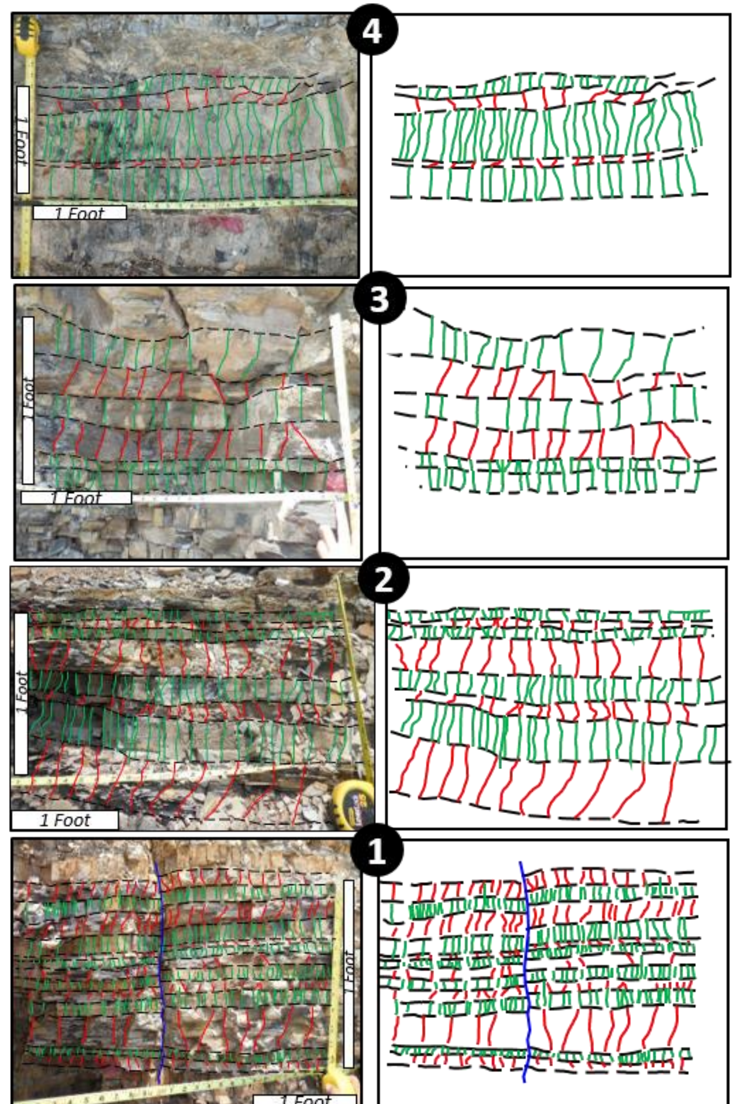
Bed thickness measured from boundary to boundary

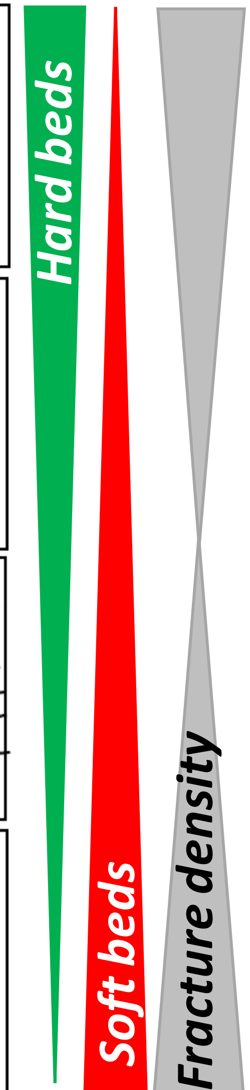
(Becerra, 2017)

I-35 Outcrop Fracture Analysis: Effects of Lithology and Bed Thickness on Fractures



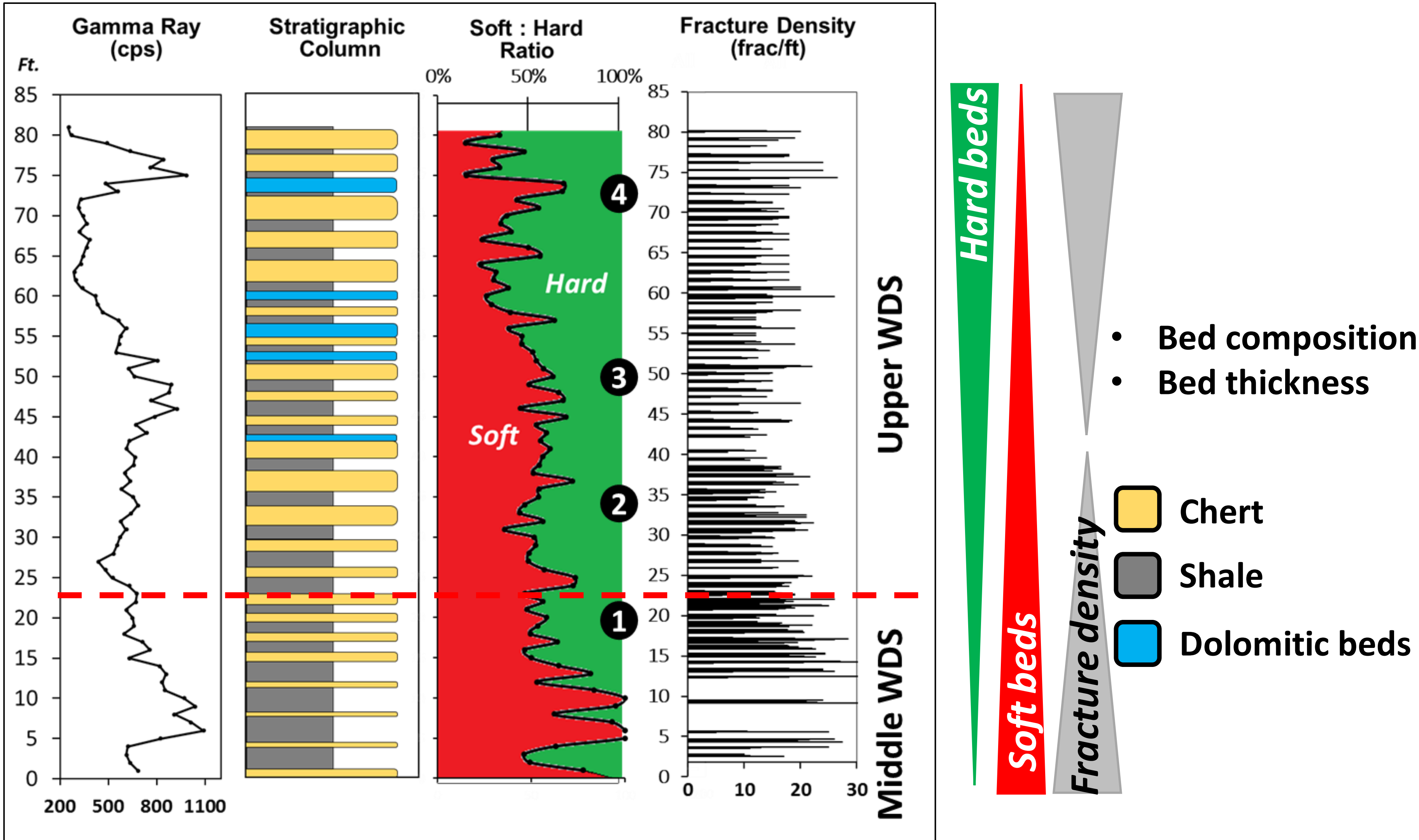






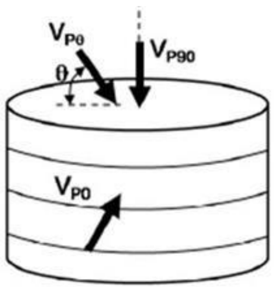
(Becerra, 2017)

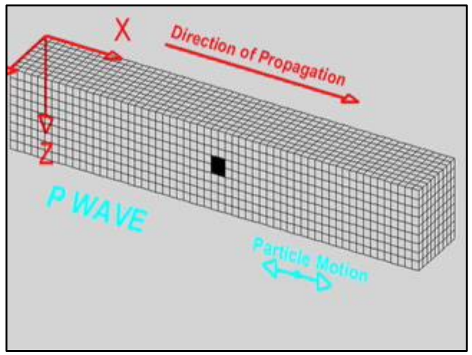
I-35 Outcrop Profile



(Becerra, 2017)

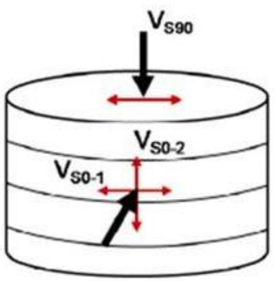
Anisotropy: Thomsen Parameters

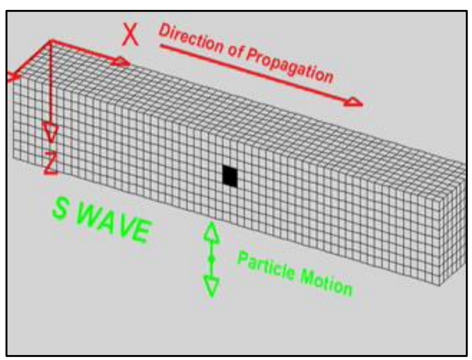




***ε** is a measure of differences in **V_p** parallel and perpendicular to lamination/bedding*

$$\varepsilon = \frac{V_p^2(0^\circ) - V_p^2(90^\circ)}{2V_p^2(90^\circ)}$$

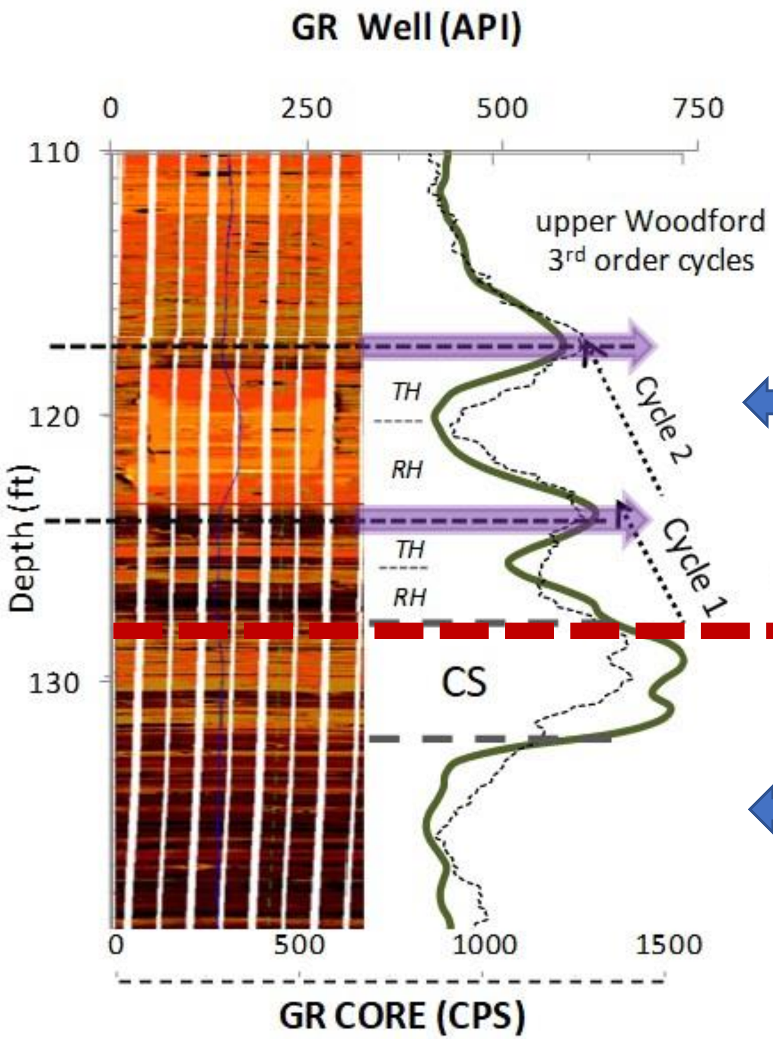




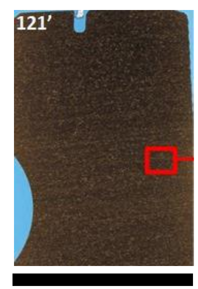
***γ** is a measure of differences in **V_{sh}** parallel and perpendicular to lamination/bedding*

$$\gamma = \frac{V_{sh}^2(0^\circ) - V_{sh}^2(90^\circ)}{2V_{sh}^2(90^\circ)}$$

Anisotropy: Woodford Shale (FMI and Core) Behind Outcrop Quarry



$$B.I. = \frac{(Q + Dol + Lm + Py)}{(Q + Dol + Lm + Cl + Py + TOC)}$$



1 inch

(Lower part of) Upper WDS
Moderately Laminated
ε = 0.17
γ = 0.18
Brittleness Index (B.I.) = 0.62

1 inch

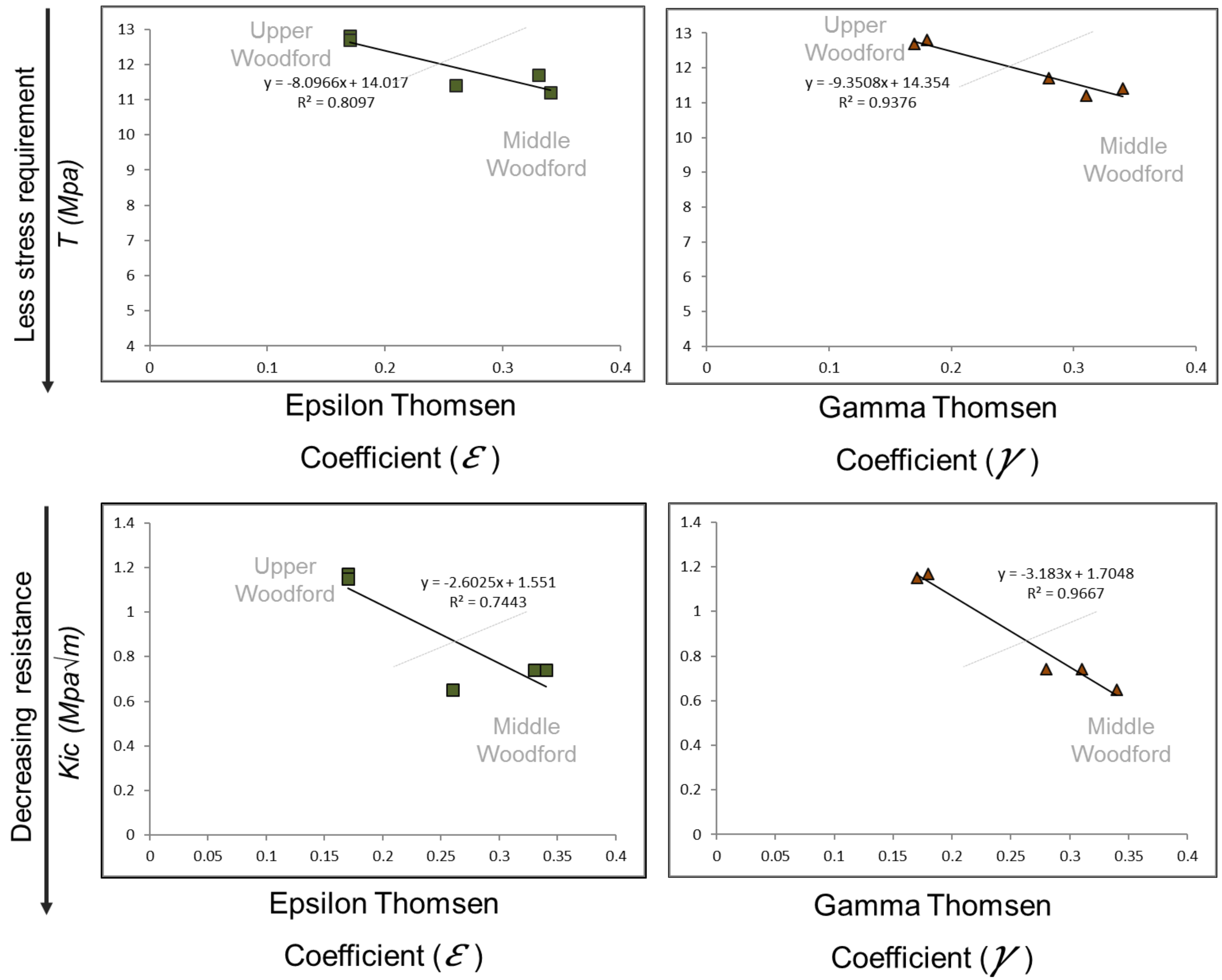
(Upper part of) Middle WDS
Highly laminated
ε = 0.26
γ = 0.34
Brittleness Index (B.I.) = 0.62

(Sierra et al., 2010)

Fractures are easily created/propagated in rocks with high anisotropy

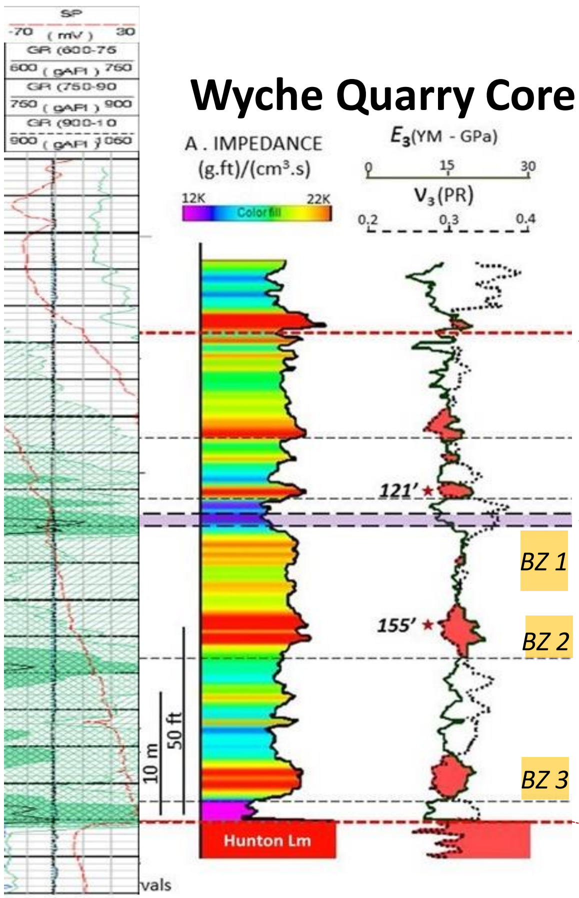
Tensile Strength (*T*)
is the maximum stress that a material can withstand before breaking

Fracture Toughness (Kic)
describes the ability of a material containing a crack to resist fracture

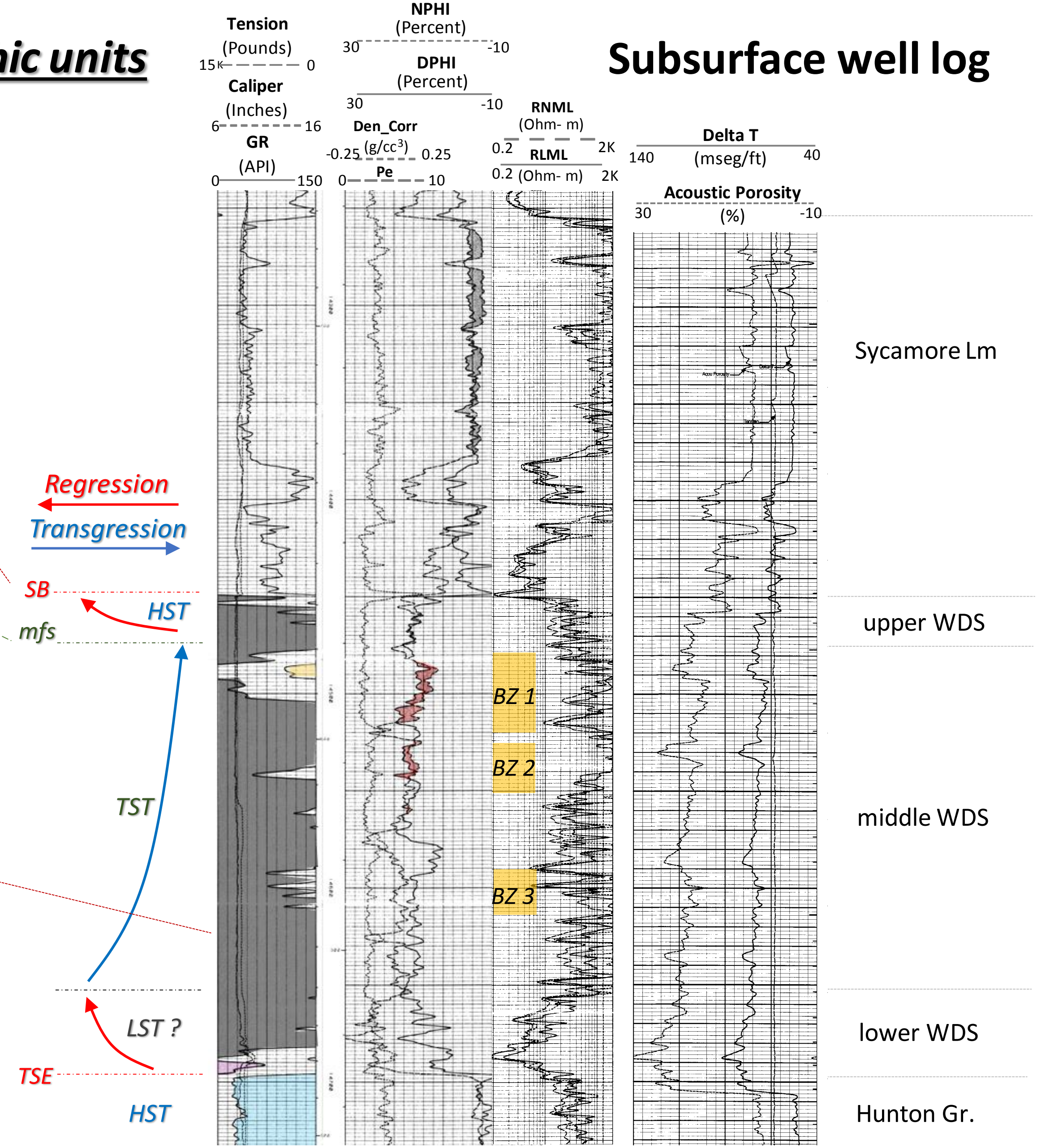


(Sierra et al., 2010; Molinares et al., 2016)

Defining mechanic-stratigraphic units

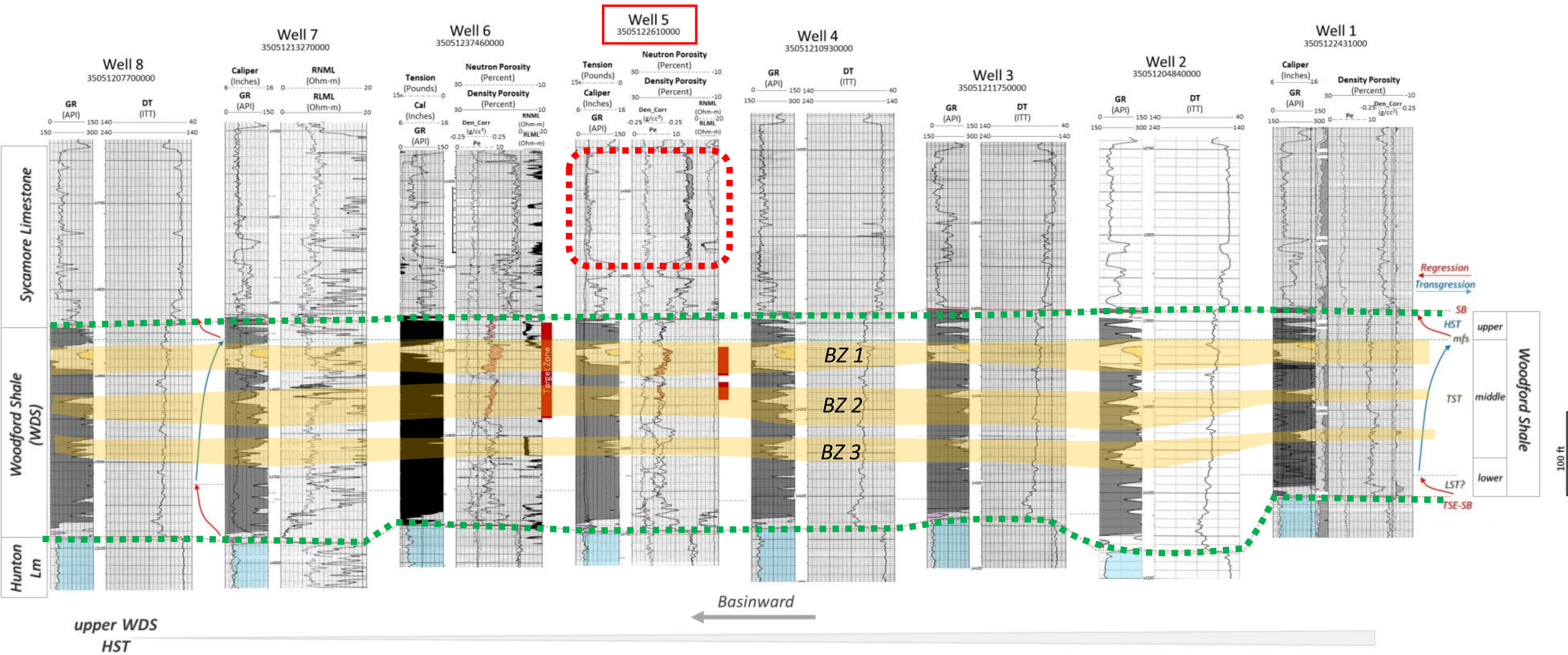


Behind outcrop core



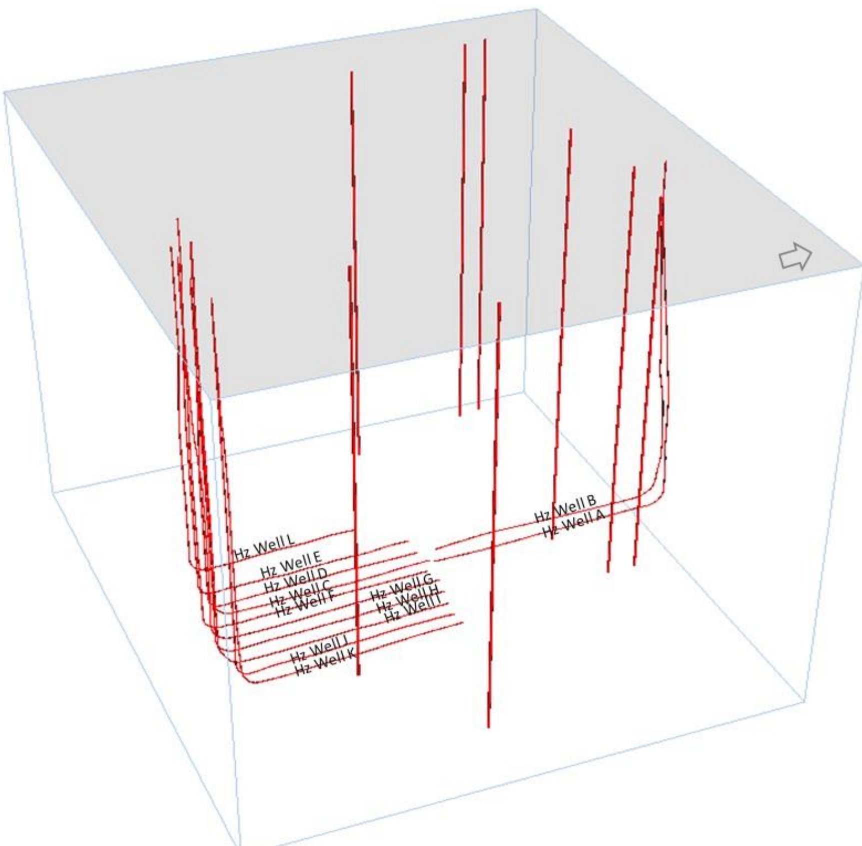
(Slatt et al., 2012; Molinares et al., 2016)

Mechanic-Stratigraphic Units



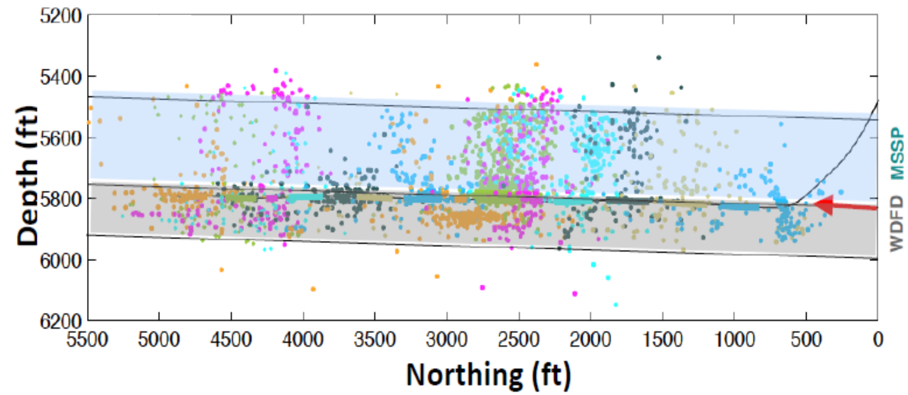
- The Woodford Shale is bounded by two unconformities
- Density-Neutron cross-over in Woodford and Mississippian intervals
- Target landing zones in BZ 1, BZ 2, and BZ 3.

Landing Zones: Subsurface

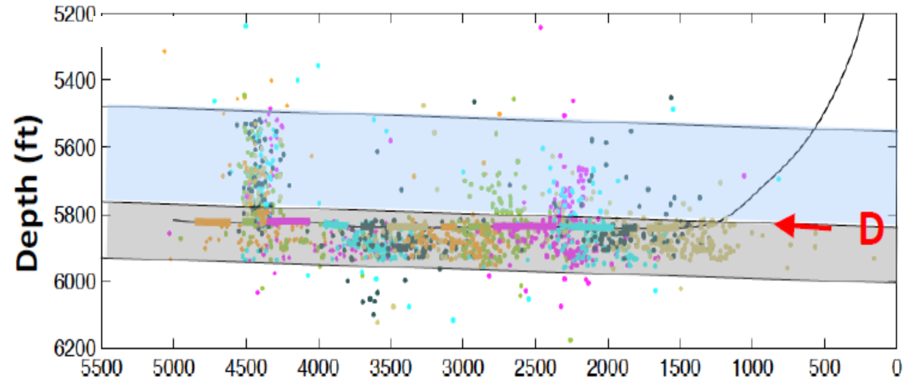


Case-Study Area

Landing Zone: Upper WDS

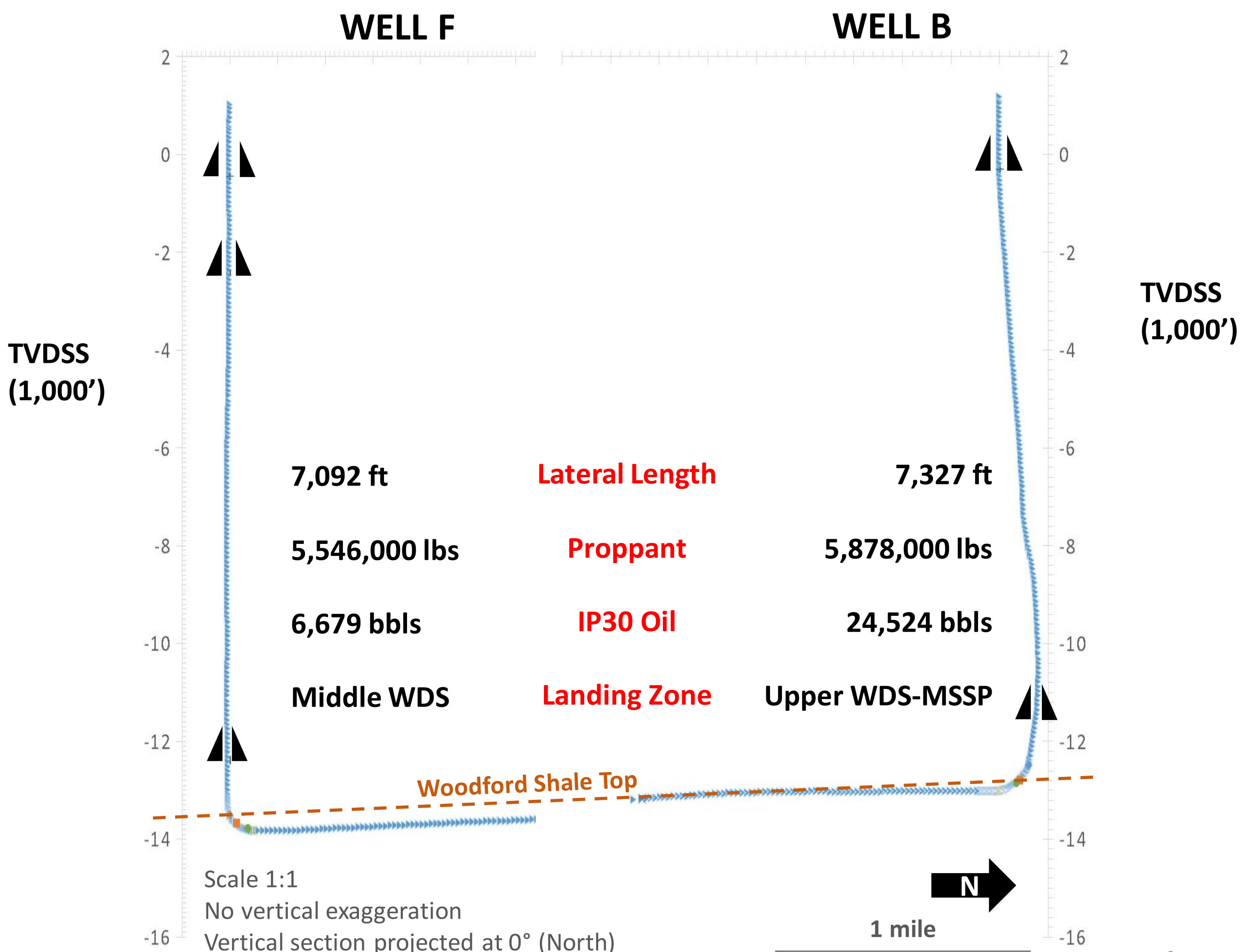


Landing Zone: Middle WDS



(Ma and Zoback, 2016)

Landing Zones: Subsurface



Sources: IHS & OCC

Conclusions

- Increased vertical anisotropy is associated with brittleness
  - Thin beds in outcrop are associated with higher fracture densities
  - Tensile Strength (*T*) and Fracture Toughness (*Kic*) are inversely correlated to anisotropy
- High (hydrocarbon) liquids production is observed in wells that have landed in the anisotropic Upper and (upper part of the) Middle Woodford Shale
- High liquids production could be associated with stimulation of some Mississippian units

Future Work

- Include more core for modeling
- Characterize Mississippian age units overlying the Woodford Shale
  - Meramec
  - Sycamore
- Employ machine learning data classification and seismic inversion for areas where core is unavailable.

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bp
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ConocoPhillips
CSE
Nostra Terra OIL & GAS COMPANY PLC
rebellion Energy
COR COUNCIL OAK RESOURCES
WARD PETROLEUM
Chevron
PAISANO ENERGY, LLC
JETTA Jetta Operating Company, Inc.
CHANDLER ENGINEERING
GASTAR
LONGFELLOW ENERGY, LP
Chaparral Energy
CASILLAS
JONES ENERGY
VITRUVIAN EXPLORATION II, LLC
PAYROCK ENERGY II
HALLIBURTON
tapstone ENERGY
OKLAHOMA CORPORATION COMMISSION
OKLAHOMA GEOLOGICAL SURVEY 1908
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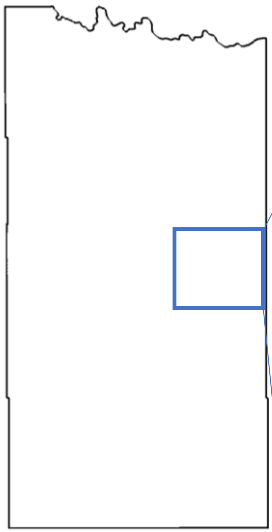
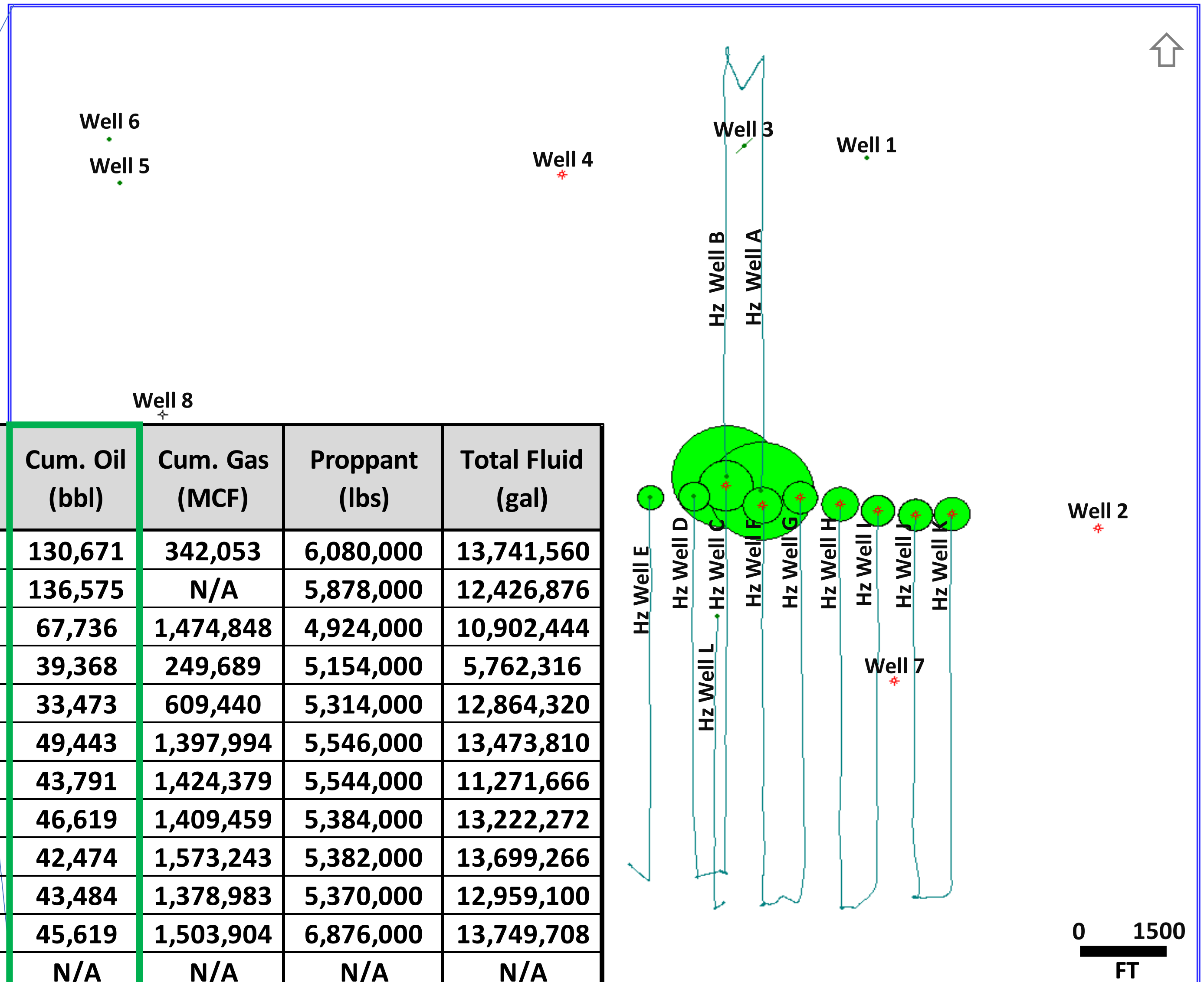
Additional Slides

Cumulative Oil Volumes





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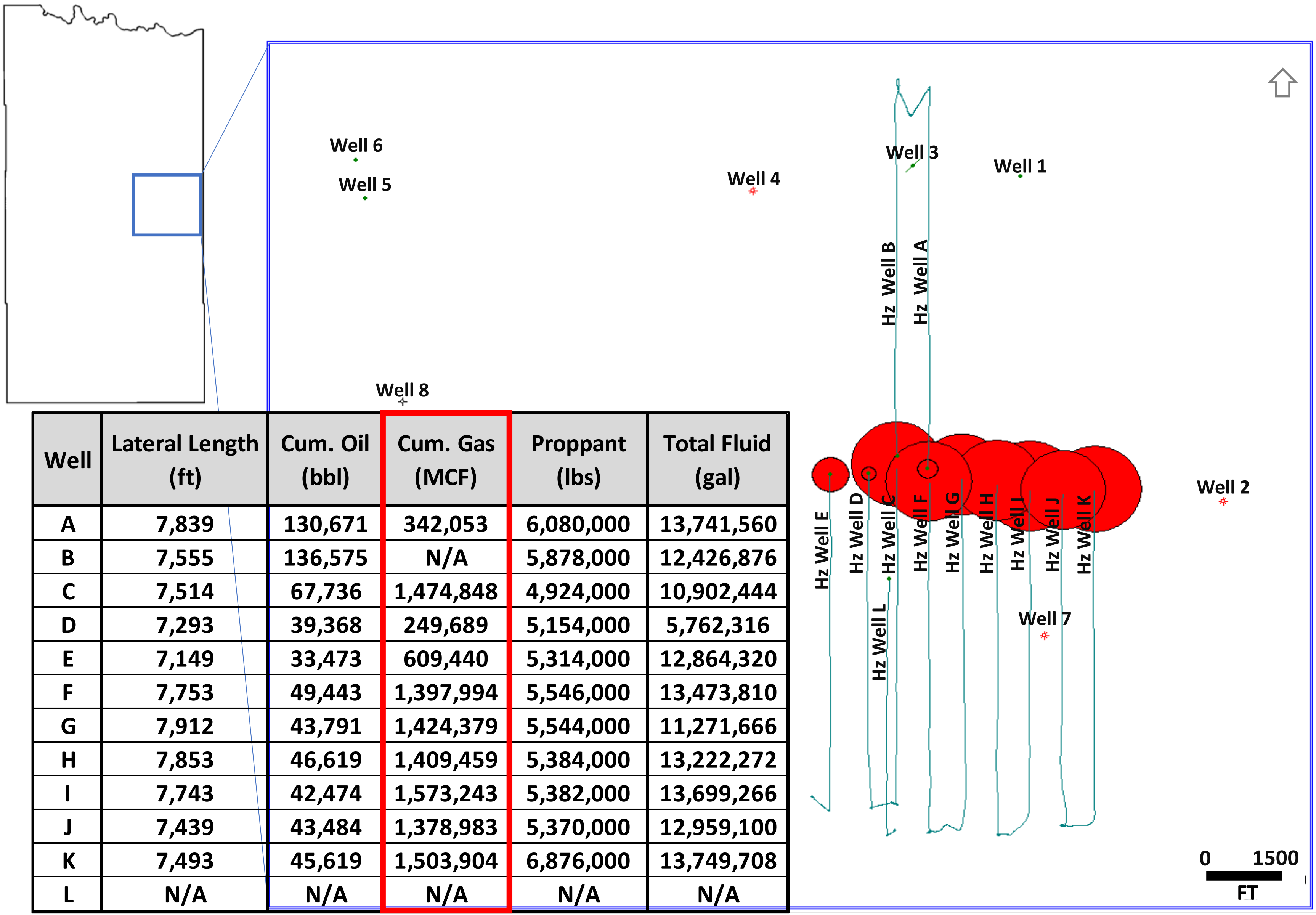
L	N/A	N/A	N/A	N/A	N/A

Cumulative Gas Volumes



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