From Reservoir Characterization, 3D Seismic multi-attribute analysis and machine learning classification to Well Performance Simulation:
A Woodford Shale Case Study in North of Oklahoma, USA

Emilio J. Torres-Parada[1], Saurabh Sinha[2],

Roger M. Slatt[1], Kurt J. Marfurt[2] and Lennon E. Infante[2]

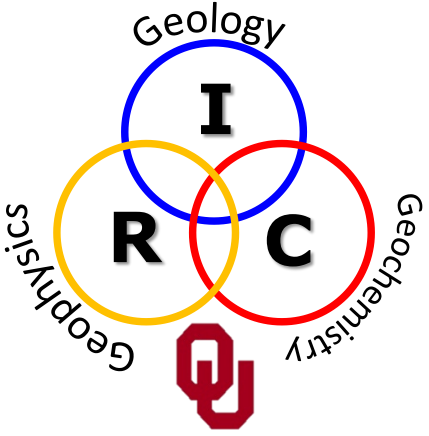
The University of Oklahoma

School of Geology and Geophysics

[1]Institute of Reservoir Characterization (IRC) consortium

[2]Attribute Assisted Seismic Processing and Interpretation (AASPI) consortium

Collaboration



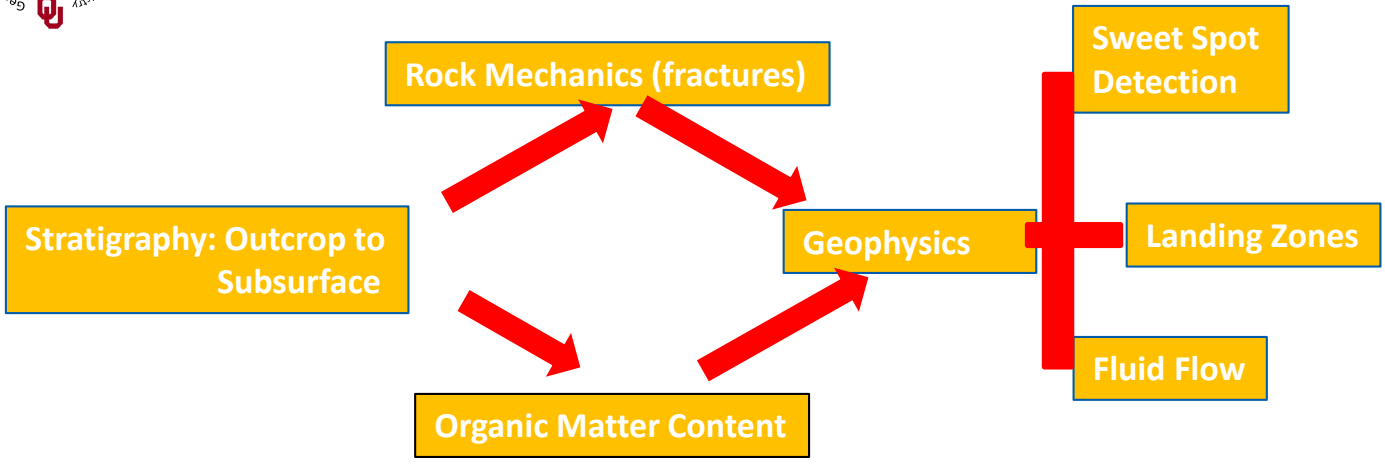
Institute of Reservoir Characterization, OU

Attribute Assisted Seismic Processing and Interpretation (AASPI), OU

Presentation Outline

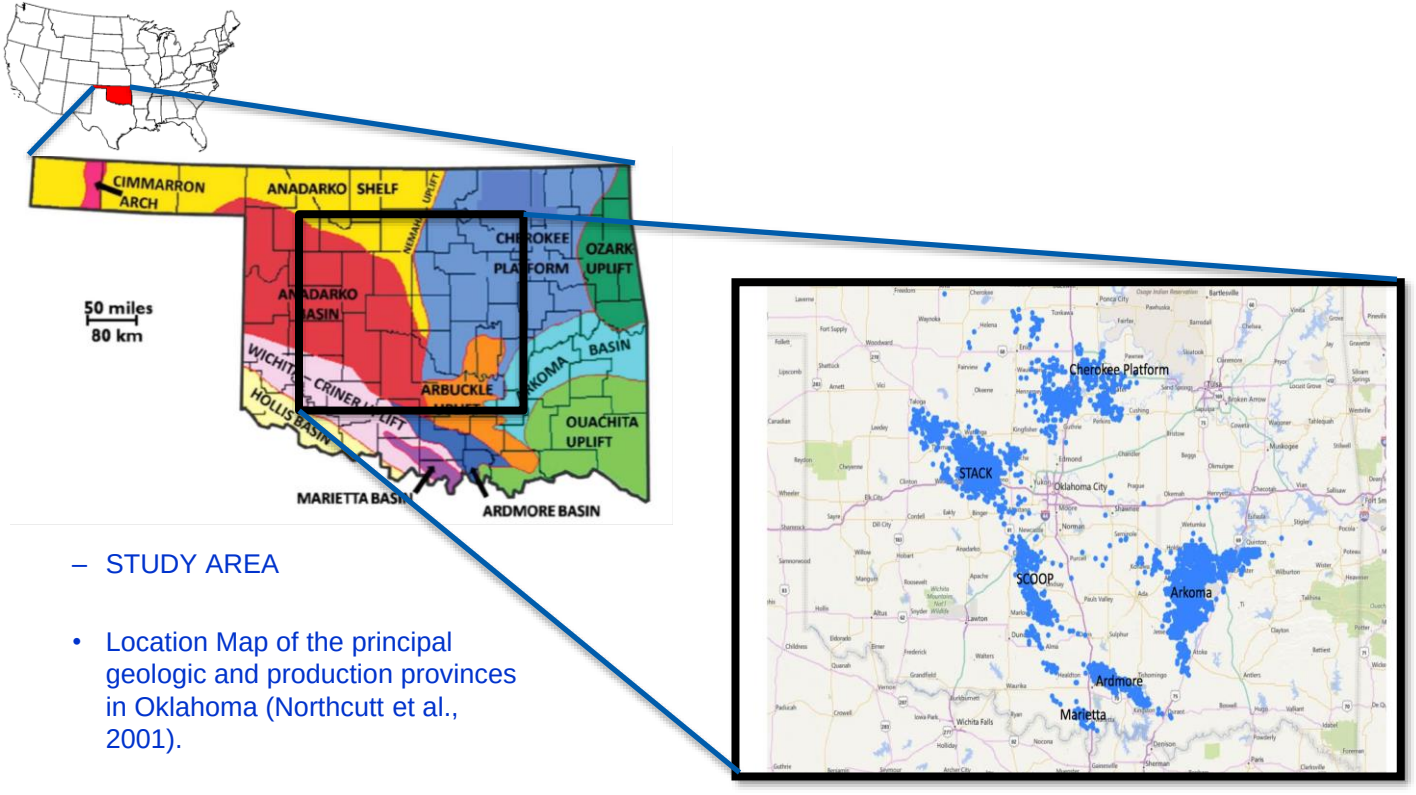
1. Introduction
2. Integration Workflow
3. Geo-cellular model
4. 3D seismic classification (SOM, GTM, K-means)
5. 3D unconventional reservoir properties modeling
6. Type Curve classification
7. Simulation
8. Conclusions

The value of integration



(Institute of Reservoir Characterization, 2018)

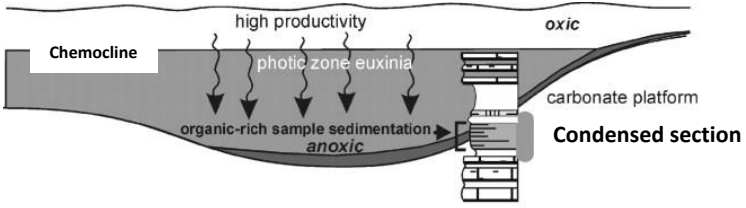
Woodford Shale location

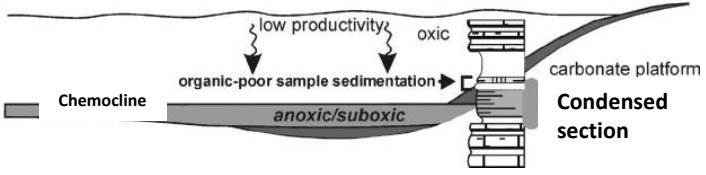


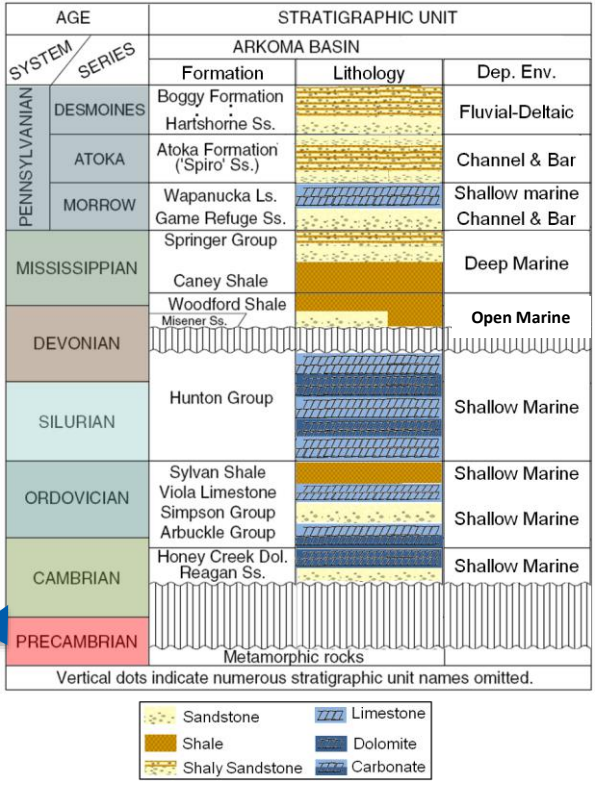
– STUDY AREA

- Location Map of the principal geologic and production provinces in Oklahoma (Northcutt et al., 2001).

What do why mean by top Woodford shale sweet spots?

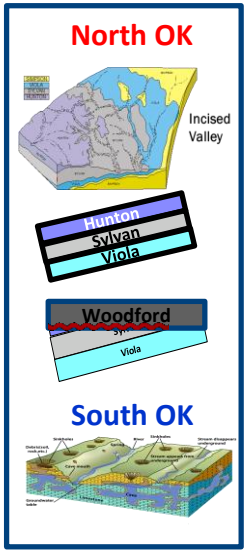


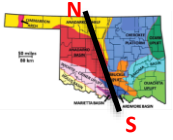


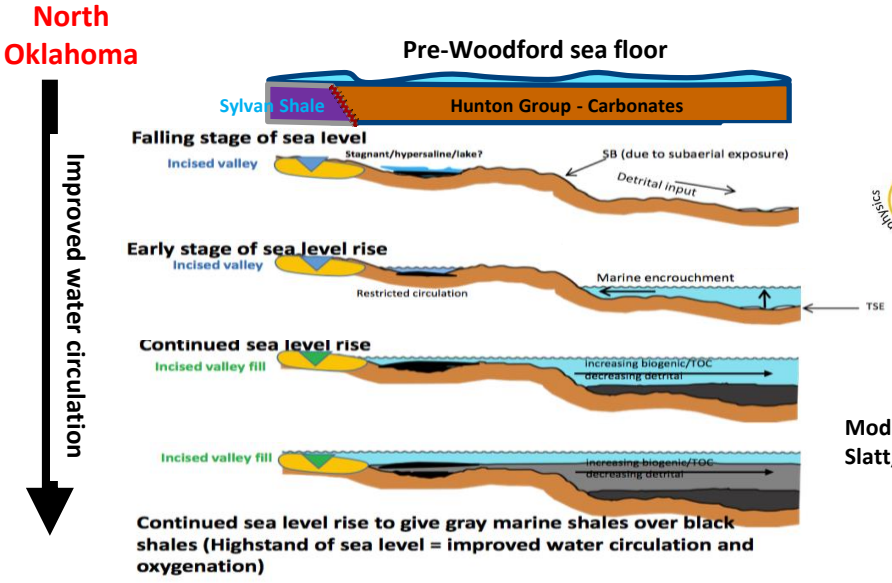


- Stratigraphic chart for the Arkoma Basin, southeastern Oklahoma (Perry, 1995 in Portas, 2009).

IRC Depositional Models from North to South through Woodford shale sea level cycles

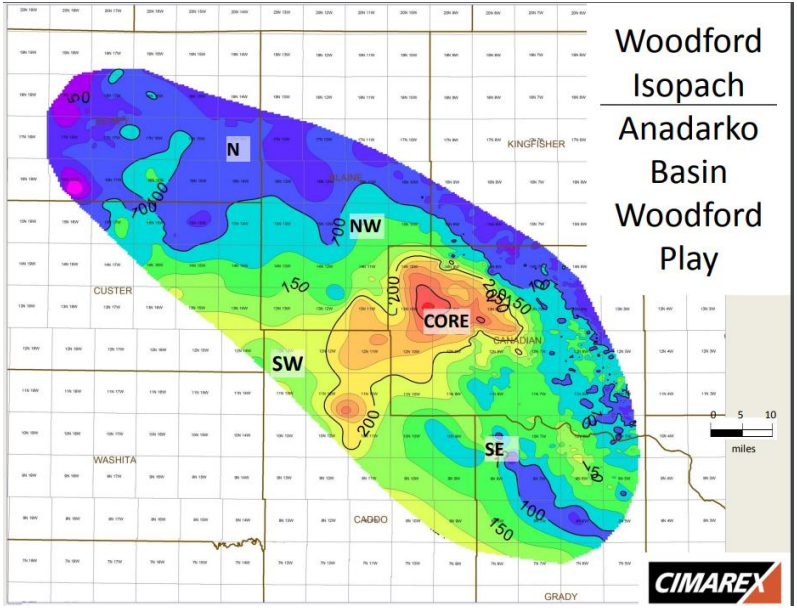






- The early stage of falling sea level may result in water mass isolation and restricted water circulation over topographic depressions left by karst/incised valley development on the underlying carbonate platform.

Woodford Shale regional depositional fairway



- The areas where the Woodford thickens correspond to the areas where the Hunton thins = Cana Field
- There is an inverse relation between thickness of the Hunton unconformity and the overlying Woodford Shale.

Craig D. Caldwell, 2013. Cana Woodford Shale Play, Anadarko Basin: The Effects of Mudrock Lithologies and Mechanical Stratigraphy on Completion and Production. OGS Oklahoma shale gas and oil workshop 2013

Important of Woodford shale Depositional Fairways For rock mechanics

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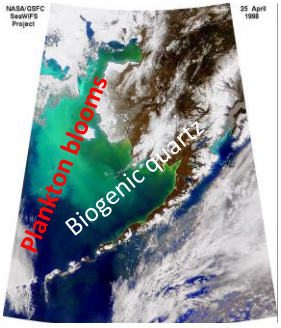
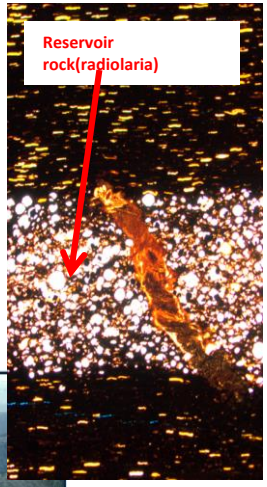
Biogenic sediments

Brooks, 2016

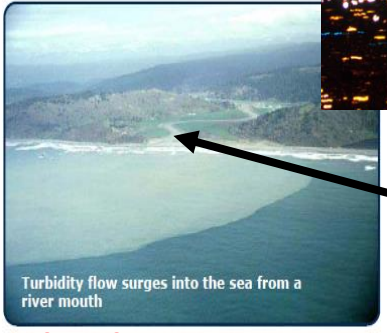




- Brittle layer
- Higher Brittleness layer

Galvis, 2017
Becerra, 2017
Ghosh, 2017

Biogenic-rich



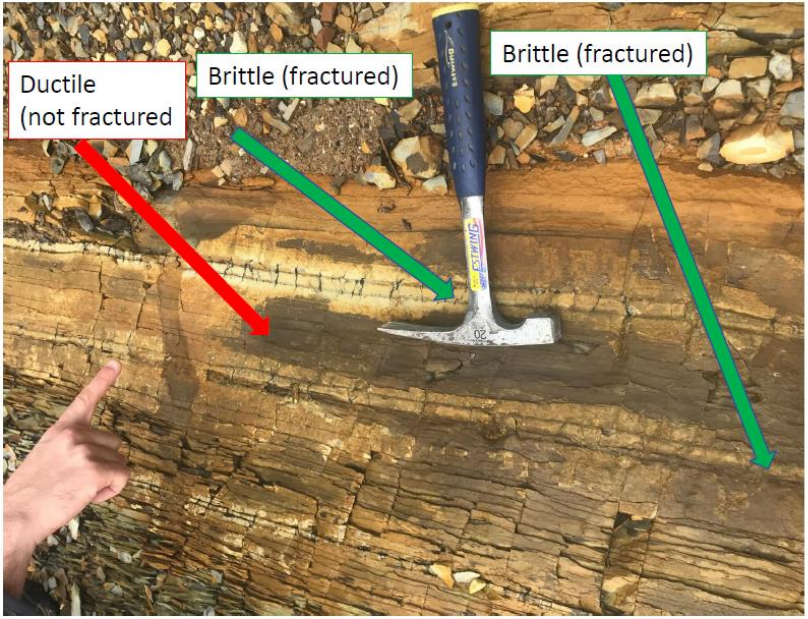
Clays, detrital quartz, TOC

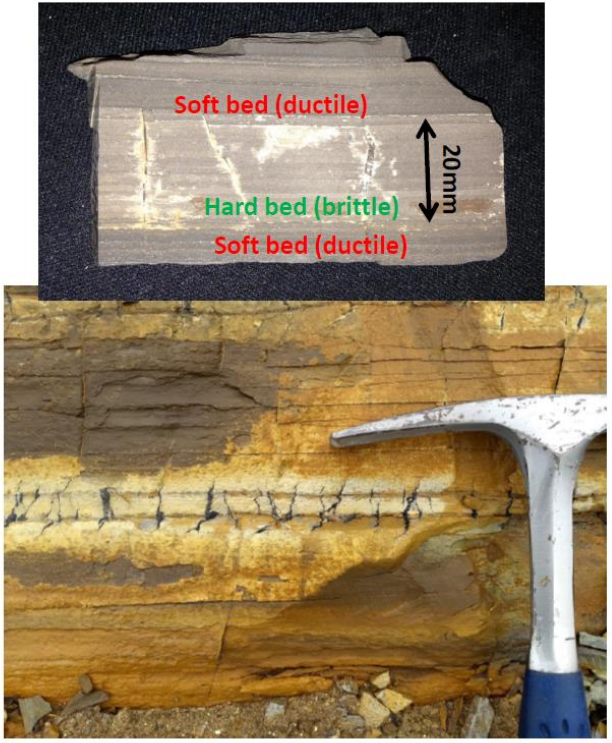
Detrital-rich

Detrital sediments

Slatt and Torres, OCGS April 2018 luncheon

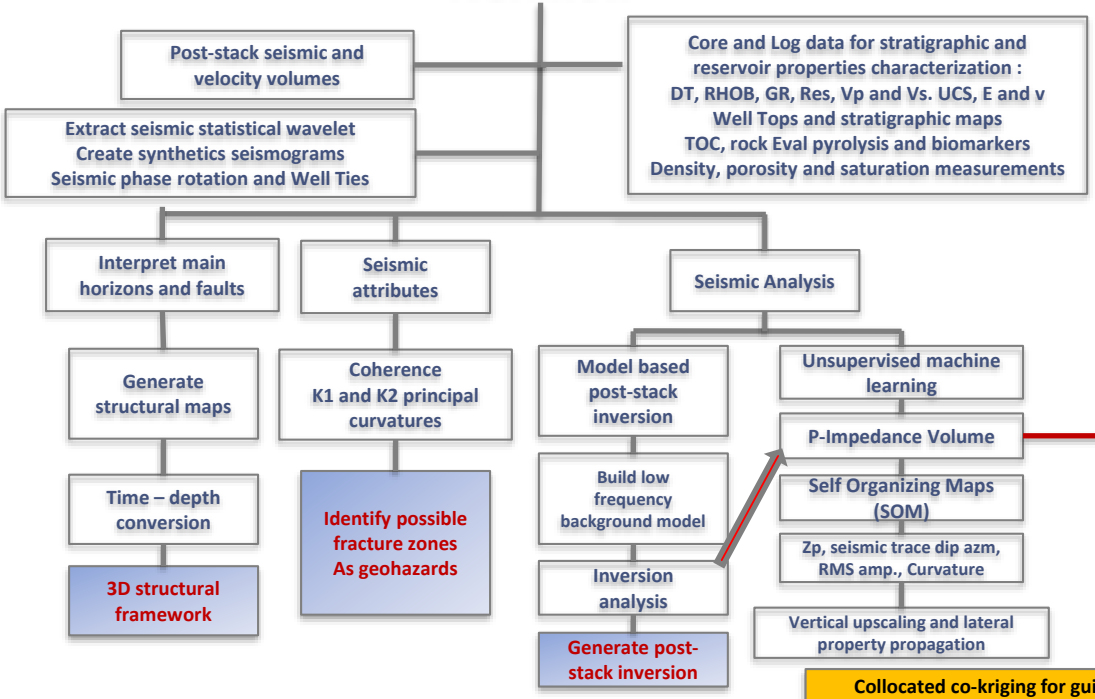
Woodford shale rock mechanics



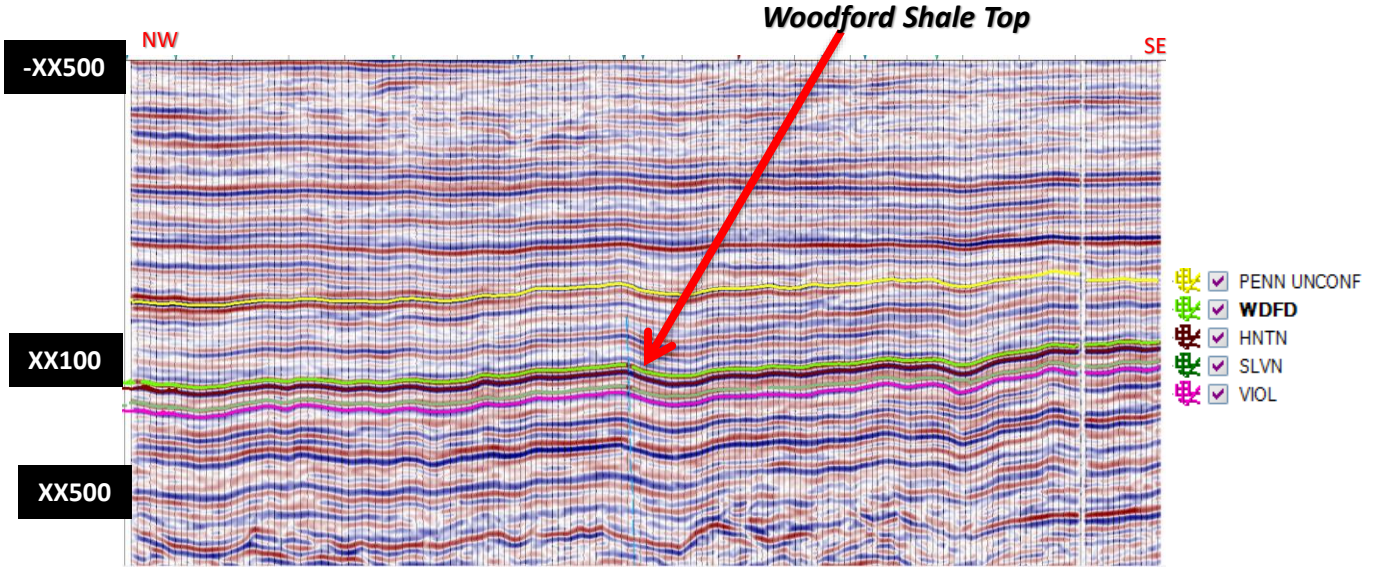


Brittle (reservoir)-Ductile (organic rich source rock) couplets seen in outcrops ('Brittle-ductile couplets' after Slatt and Abousleiman, 2011)

Proposed Geo-cellular Modeling Workflow

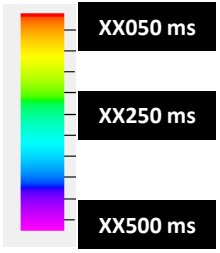


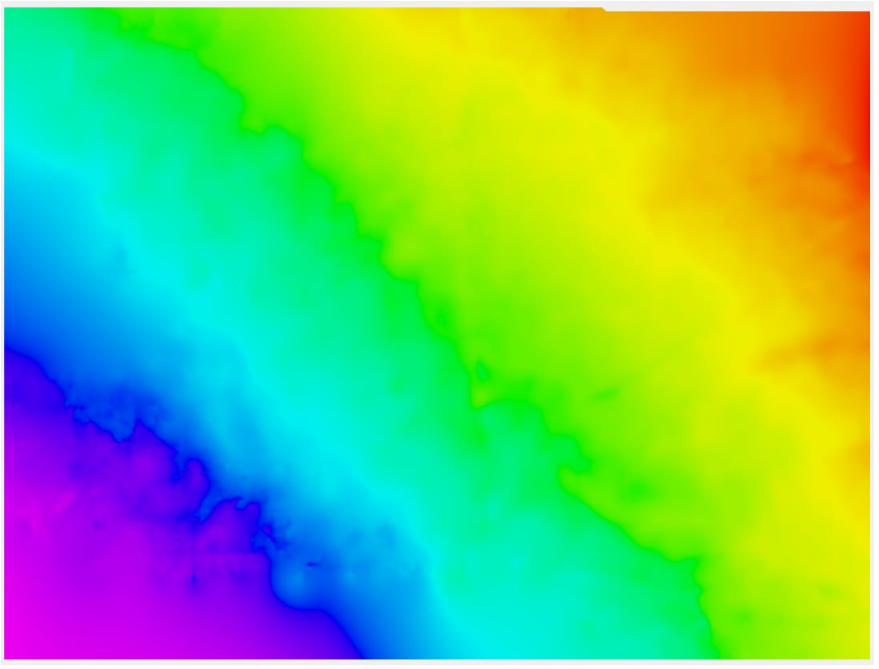
Seismic Interpretation and Well Control

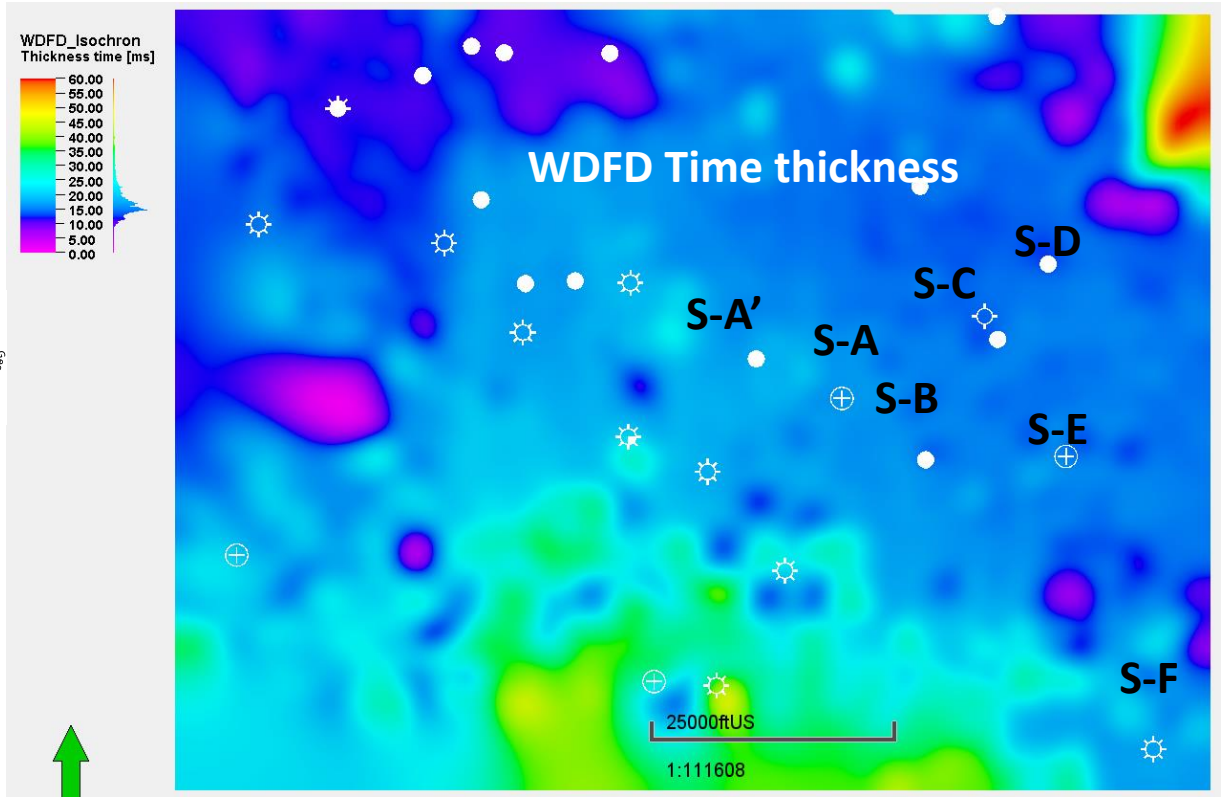


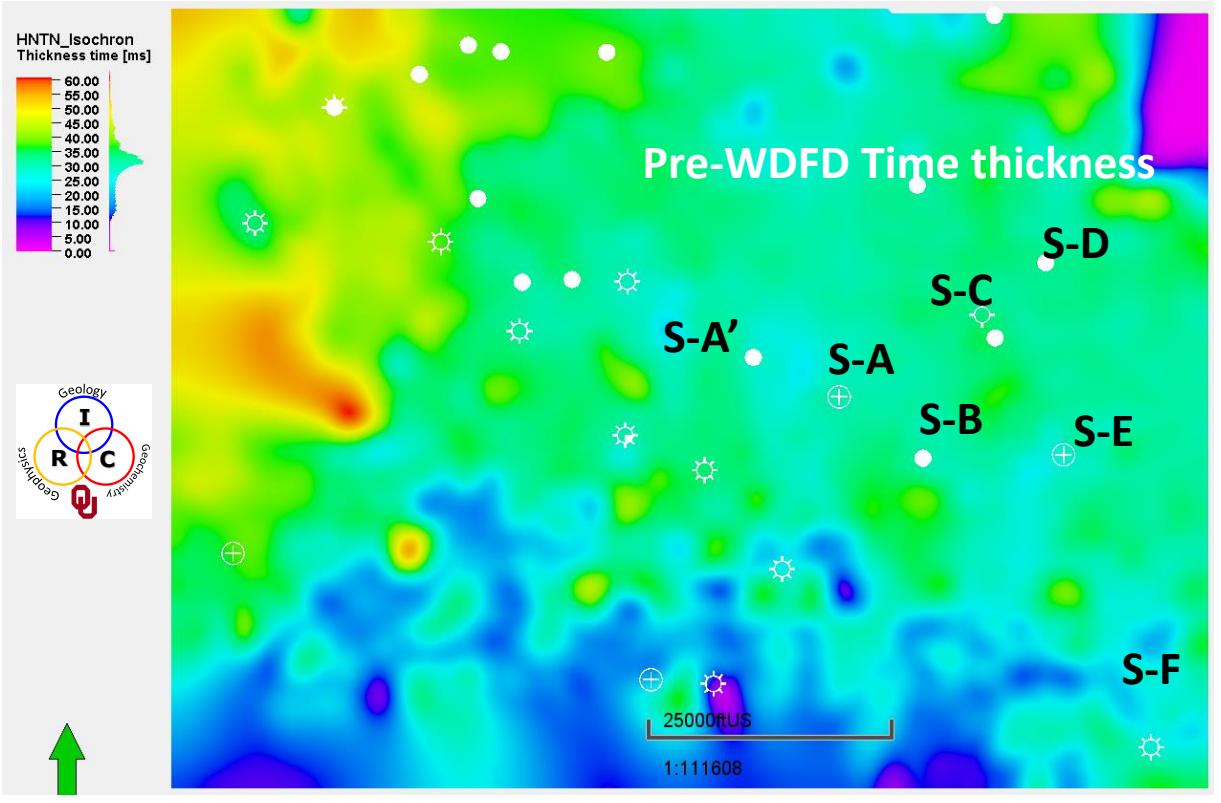
Total 21 wells available with sonic and density logs

WDFD Time structure map (ms)

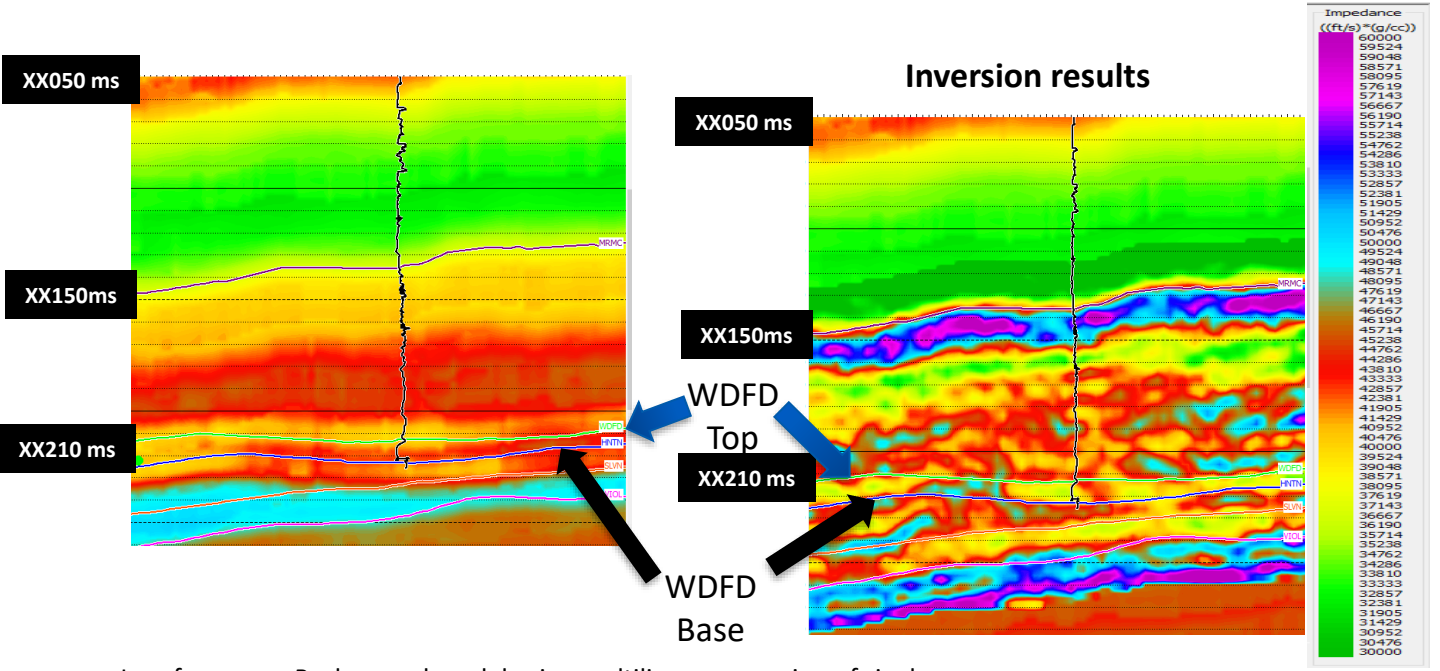





WDFD_Isochron
Thickness time [ms]
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
WDFD Time thickness
S-A'
S-A
S-B
S-C
S-D
S-E
S-F
25000ftUS
1:111608


HNTN_Isochron
Thickness time [ms]
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Pre-WDFD Time thickness
S-D
S-C
S-A'
S-A
S-B
S-E
S-F
25000ftUS
1:111608

Post Stack inversion Results



Low frequency Background model using multilinear regression of single well models and instantaneous frequency and phase attributes

Machine learning Classification Methods

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Let's get some seismic facies in my shale reservoir!

- K-means
- Self Organizing Maps (SOM)
- Generative Topographic Mapping (GTM)
- Support Vector Machine (SVM)
- Gaussian Mixure Models (GMM)
- Artificial Neural Networks (ANN)

(Meldahl et al., 2011; Roy and Marfurt, 2013; Snyder, 2016; Zhao et al., 2016; Qi et al., 2016; Infante-Paez, 2018)

Machine learning Classification Methods

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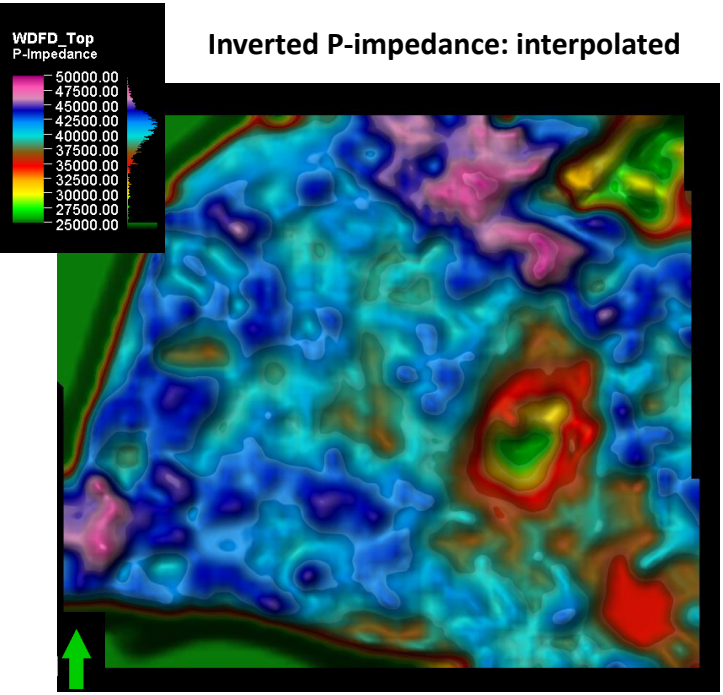
When is a coffee mug a donut? Topology explains it

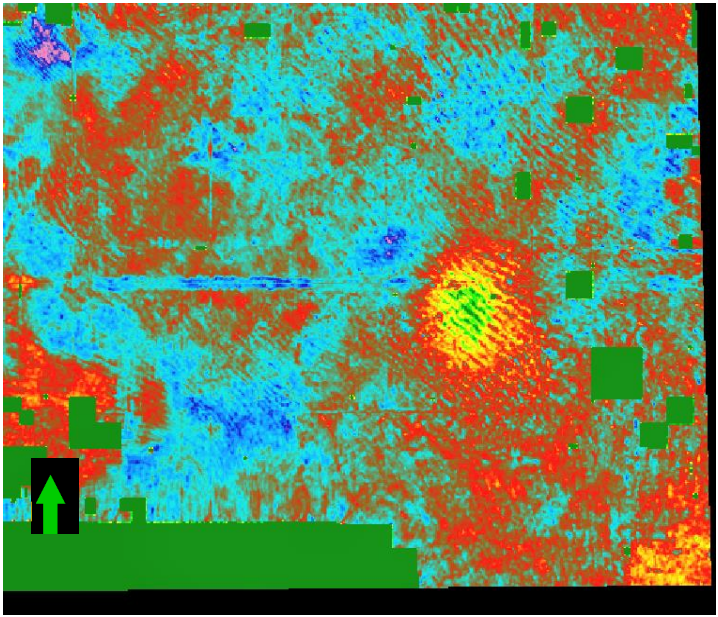
http://www.gmanetwork.com/news/scitech/science/583886/when-is-a-coffee-mug-a-donut-topology-explains-it/story/

(Meldahl et al., 2011; Roy and Marfurt, 2013; Snyder, 2016; Zhao et al., 2016; Qi et al., 2016; Infante-Paez, 2018)

Petrophysical properties upscaling and variogram distribution for lateral interpolations based on collocated co-kriging



Inverted P-impedance: interpolated



Self Organizing Map (SOM)

Geomechanical Properties from Well Logs

Young's Modulus

$$E = \frac{\rho V_s^2 \left(3V_p^2 - 4V_s^2\right)}{\left(V_p^2 - V_s^2\right)}$$

Poisson's Ratio

$$\nu = \frac{\left(V_p^2 - 2V_s^2\right)}{2\left(V_p^2 - V_s^2\right)}$$

Bulk Modulus

$$K = \rho V_p^2 - \frac{4}{3}\rho V_s^2$$

Shear Modulus

$$G = \rho V_s^2$$

Fracture Toughness

$$K_{ic} = 0.05E$$

Horizontal Stress

$$S_h = \left(\frac{v}{1-v}\right) S_v + \left(\frac{1-2v}{1-v}\right) \alpha\rho$$

Fracture Gradient

$$FG = \frac{S_h + T_o}{Depth(m)}$$

Geomechanical Properties from Well Logs
Reservoir modeling guided with seismic rock properties

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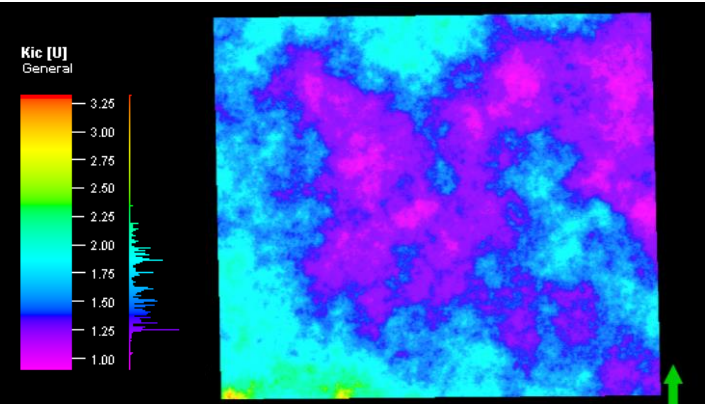
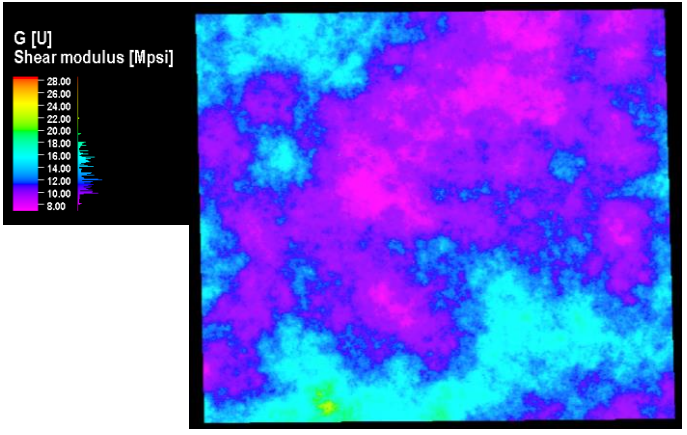
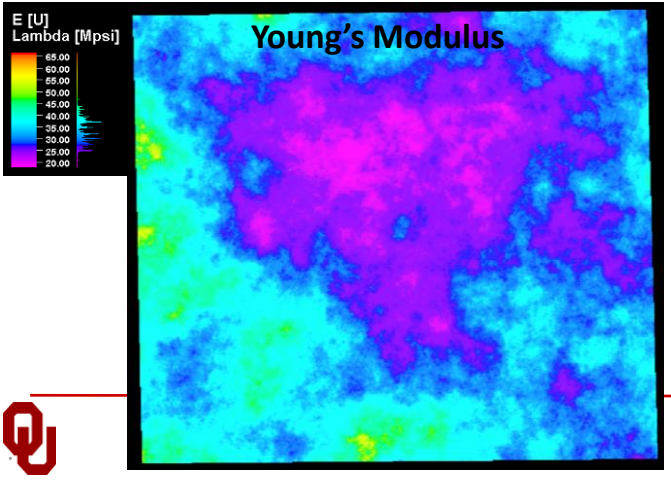
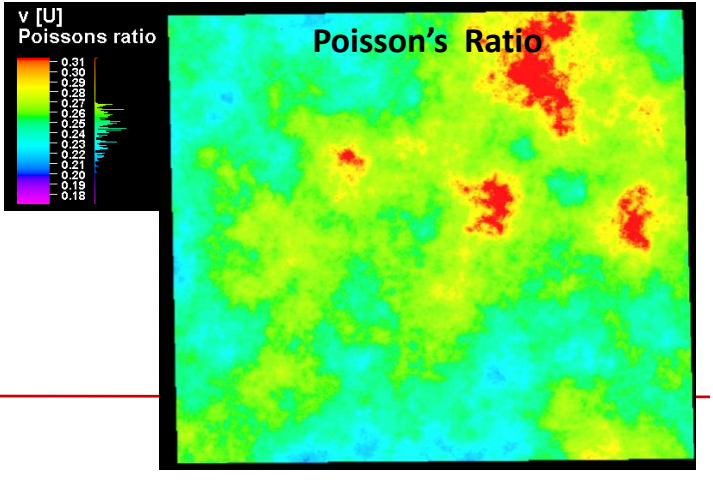
Fracture Toughness



Shear Modulus







Calculation of TOC

- **Passey's Vs. Schmocker ???**

Passey's (1990)

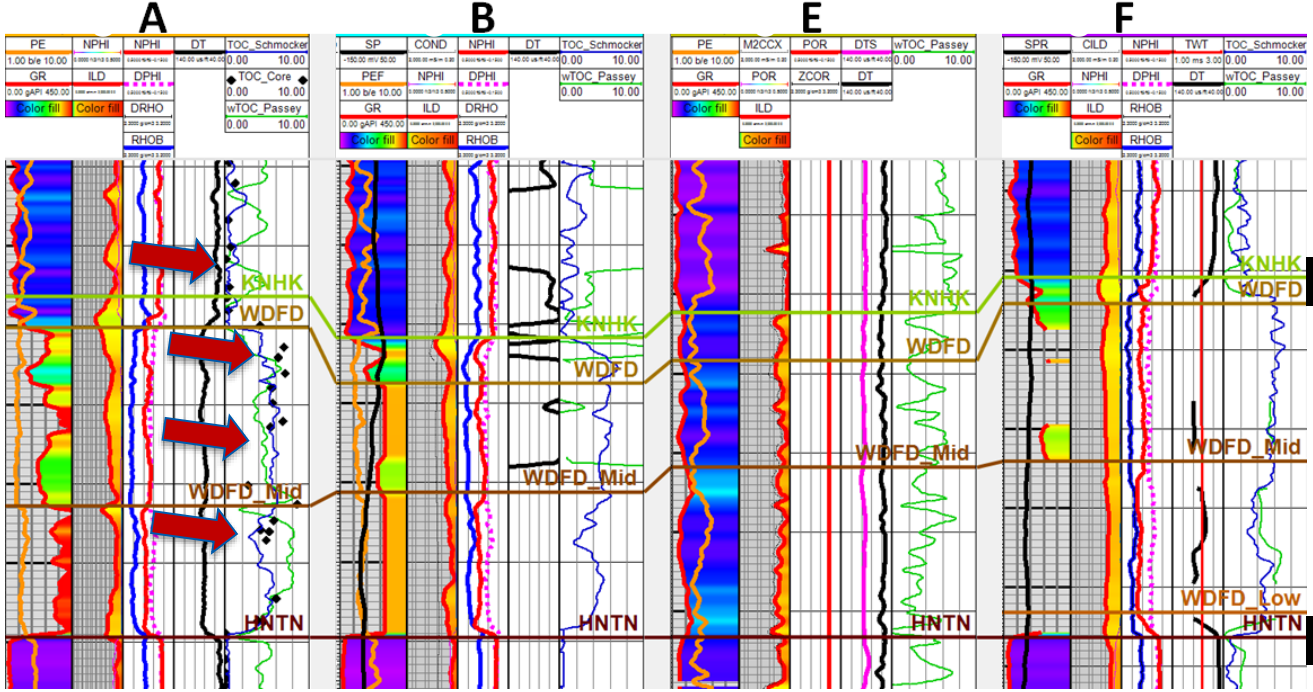
$$\Delta \log R = \log_{10}(R/R_{baseline}) + 0.02 \times (\Delta t - \Delta t_{baseline})$$

$$TOC = (\Delta \log R) \times 10^{(2.297 - 0.1688 \times LOM)}$$

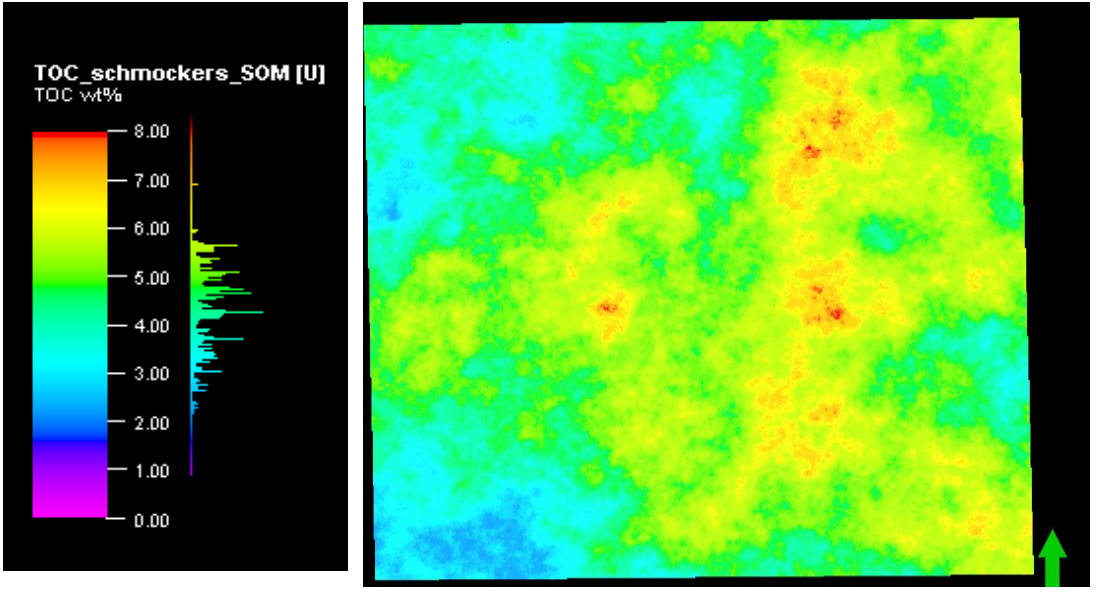
Applied Schmocker's – calibrated with core and cuttings TOC%

$$TOC\ [wt\%] = [(-56.547 * RHOB) + 154.867] / 2$$

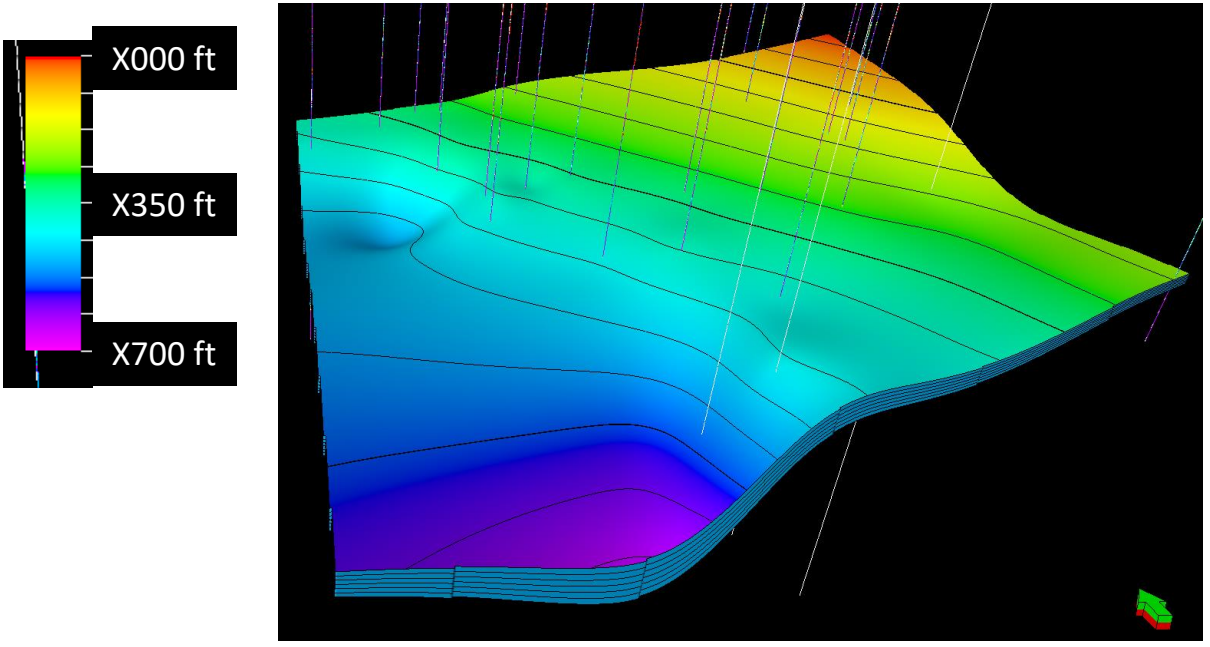
Calculation of TOC with well logs



TOC Calculation – Average in zone of interest



Reservoir model

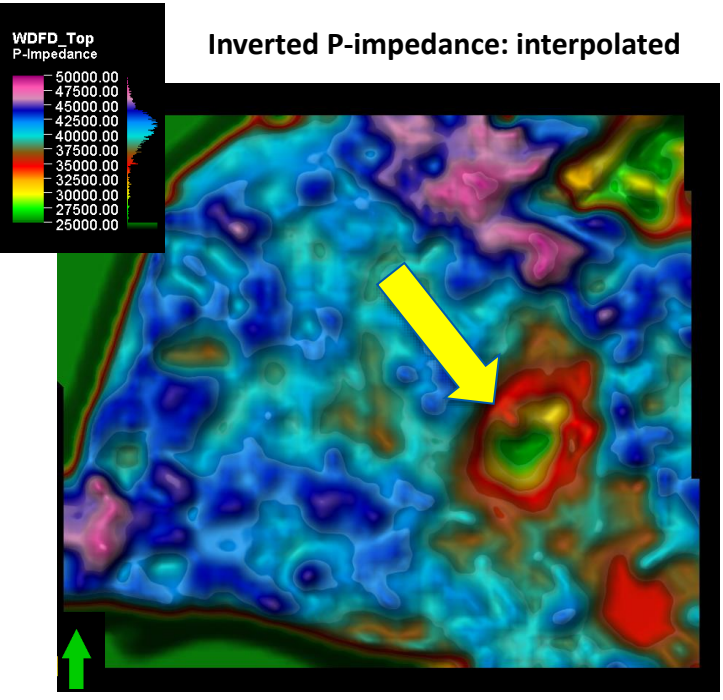


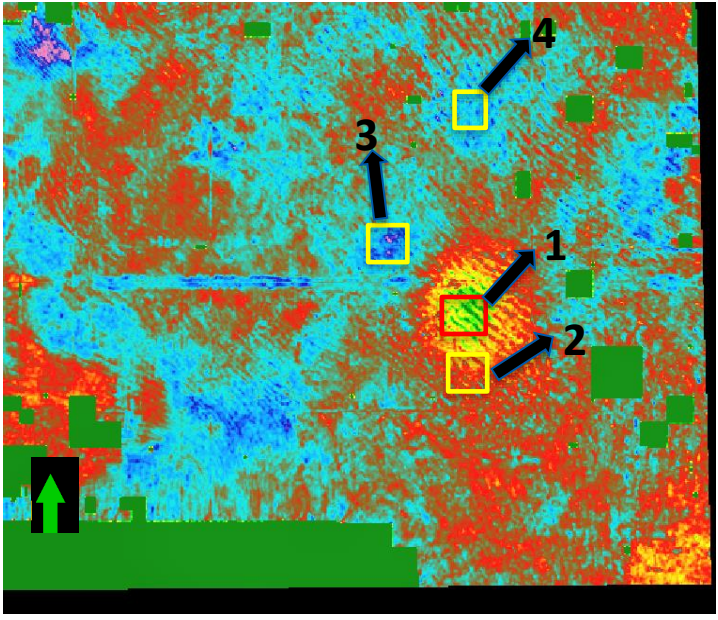
Vertical Exaggeration:10

Reservoir simulation – area selection

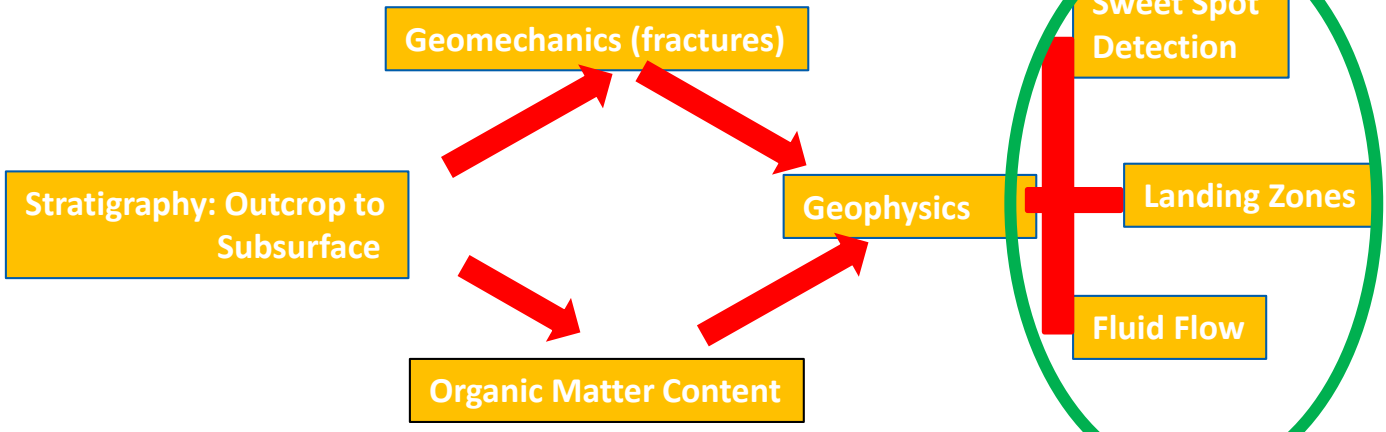
Inverted P-impedance: interpolated

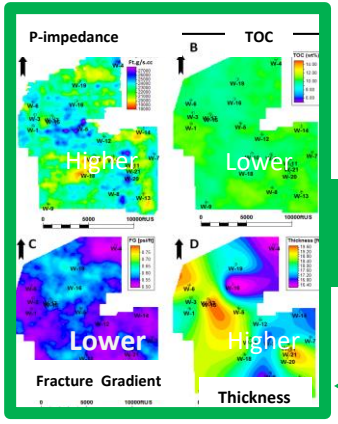
Self Organizing Map (SOM)



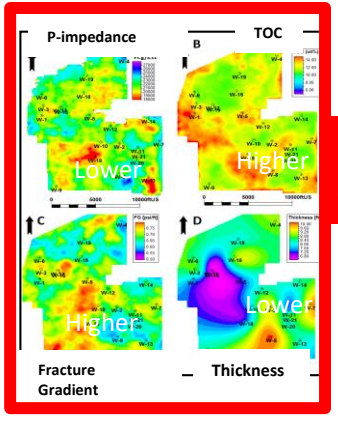


The value of integration

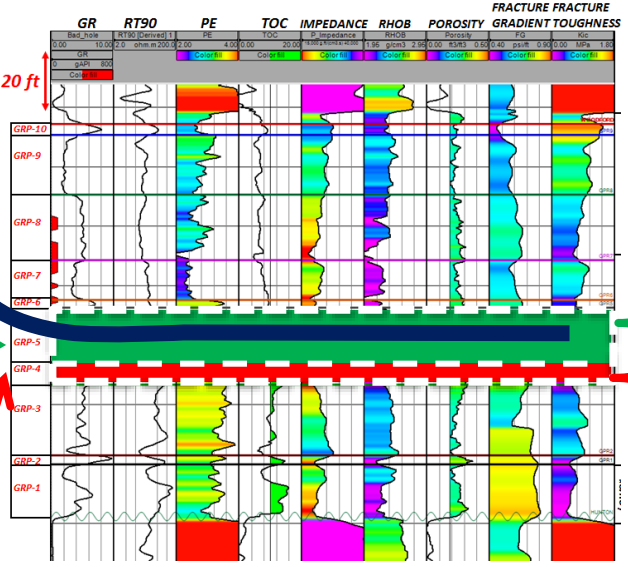




GRP-5



GRP-4



GRP-5 mainly hard beds.

GRP-4 Mainly Soft beds

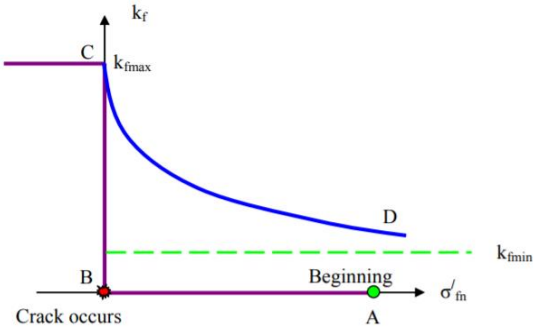
Identify areas with:

- **High Thickness**
- **Low FG (brittle)**
- High TOC
- **High impedance**

Geology
Geophysics
Geochemistry
I
R
C

Coupled Simulation

Geomechanical Coupling (Fully coupled, two way)

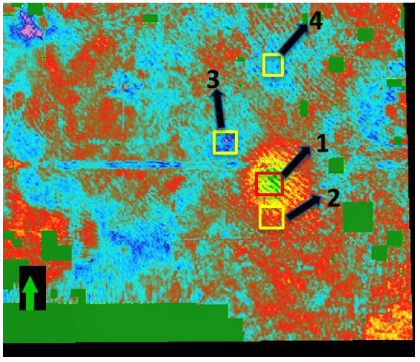


Conceptual implementation of Barton – Bandis model (after Tran et al., 2009).

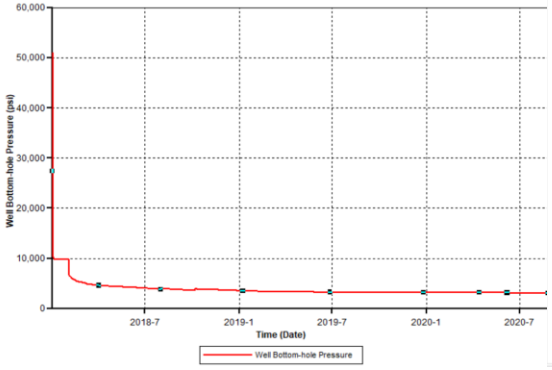
Fluid Model

- Rich Condensate
- Seven Lumped components
- Same for all TC areas
- Primary aim is to see geology variations

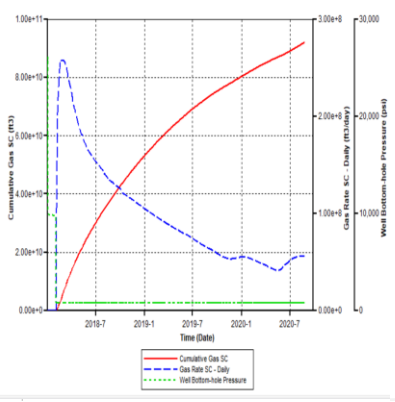
Self Organizing Map (SOM)



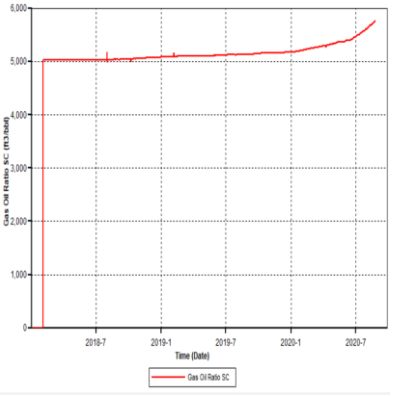
Coupled Simulation: Geomechanical properties + fluid flow



Well bottom-hole pressure for the injection.



Gas rate, BHP and cumulative gas for Area 1 well



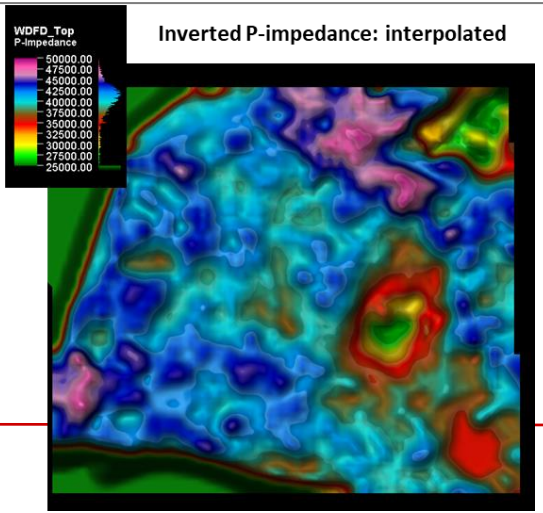
Gas oil ratio for area 1 well

- **5,200 ft lateral length**
- **Fracture stage every 220 ft.**
- **250,000 gallons slick water**
- **Dew point 4,200 PSI**
- **0.65 specific gravity**
- **55 API Gravity**

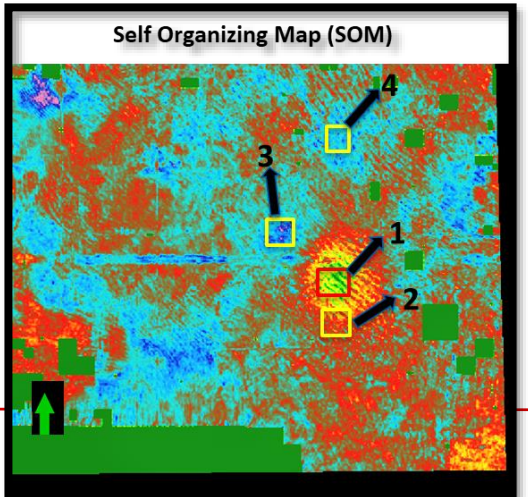
EUR Summary

Simulation Results	
Area	**TC Well EUR (MBOE)**
1	1802
2	1624
3	803
4	729

Operator xxx Results	
Area	**TC Well EUR (MBOE)**
1	2000
2	1702
3	1385
4	509



Inverted P-impedance: interpolated



Conclusions

- Our study identifies geological sweet spots and type curves in the Woodford shale (TOC, geomechanical parameters)
- Study shows using best of all available dataset can enormously increase the resolution and confidence on static model
- Results show multi-attribute analysis provide a promising alternative way of deriving the type curves
- Geomechanical simulation provides a robust way to model gradual closing of fractures and hence a time variant “shrinking” simulated rock volume instead of conventional history matching with multiple permeability zones

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A HUGE THANK YOU!!!

- Henry Galvis
- Daniela Becerra
- Dr. Sayantan Ghosh
- Dr. R. Paul Philp
- Rafael Pires da Lima

Questions?

etorres@ou.edu

rslatt@ou.edu

www.irc.oucreate.com