The University of Oklahoma
School of Geology and Geophysics
Institute of Reservoir Characterization (IRC)

Geology of the Woodford Shale in Oklahoma

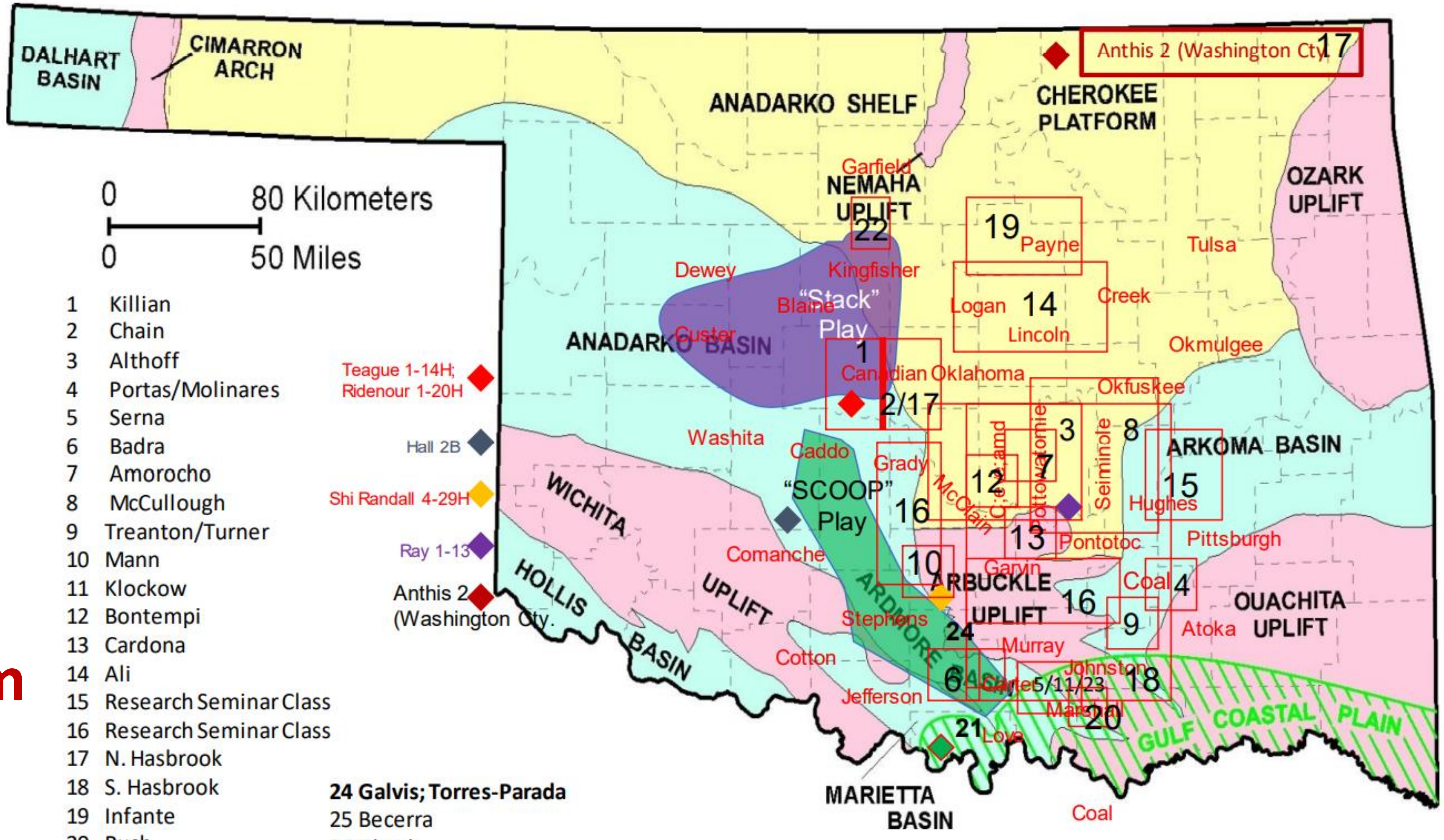
Richard Brito* and Roger Slatt
Collaborators: Henry Galvis, Emilio Torres, Daniela Becerra and Past IRC Graduate Students

Oklahoma Geological Survey
Shale Resources Plays of Oklahoma – Online Workshop – November 2020

OU Woodford Shale Consortium

Roger Slatt (1941-2020)

Woodford Shale Consortium Thesis/Dissertation Areas

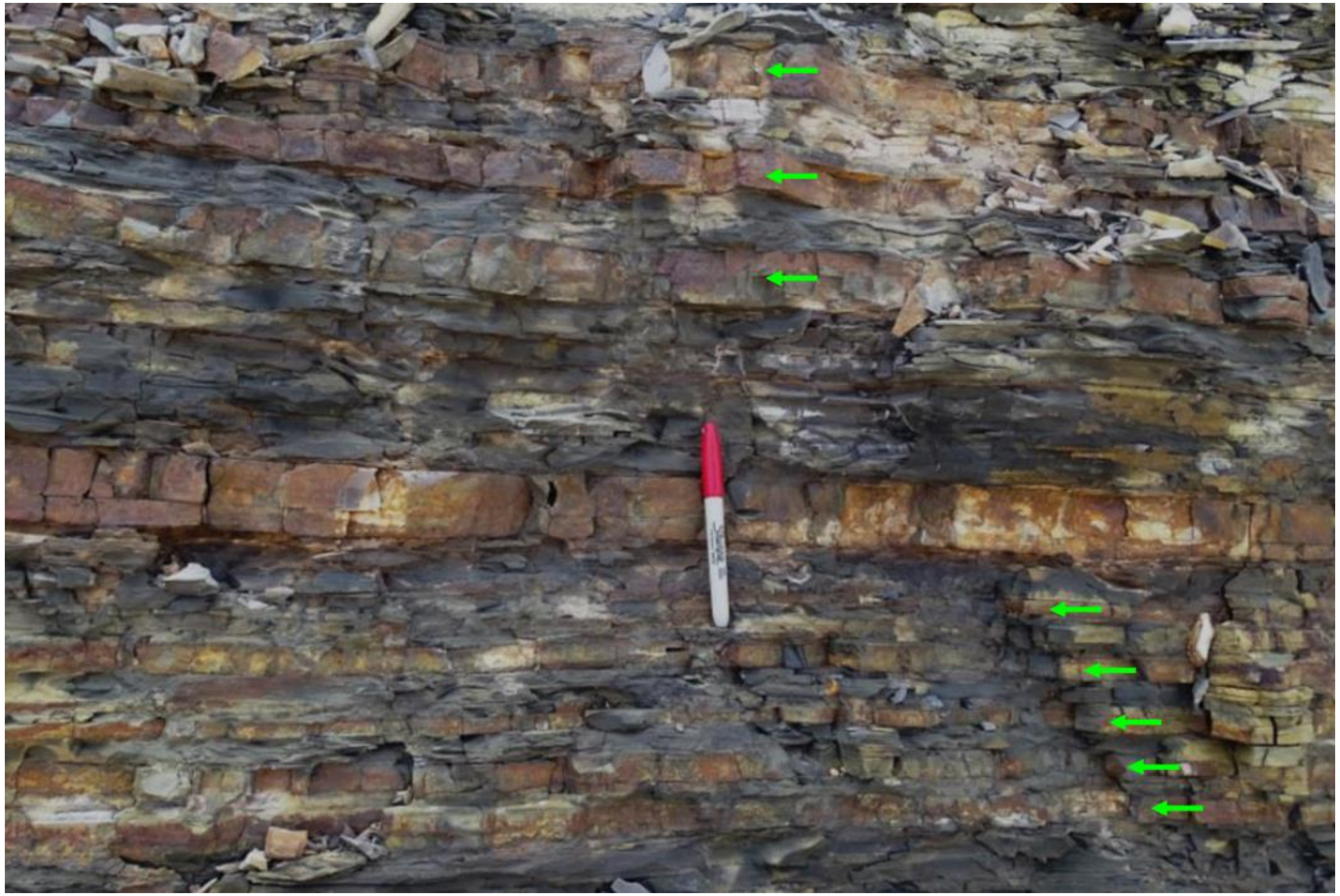


1 Killian
2 Chain
3 Althoff
4 Portas/Molinares
5 Serna
6 Badra
7 Amorocho
8 McCullough
9 Treanton/Turner
10 Mann
11 Klockow
12 Bontempi
13 Cardona
14 Ali
15 Research Seminar Class
16 Research Seminar Class
17 N. Hasbrook
18 S. Hasbrook
19 Infante
20 Rush
21 Brito
22 Zhang
23 Ifunanya
24 Galvis; Torres-Parada
25 Becerra
26 Ghosh
27 Maynard
28 Totten
29 Sierra; Molinares

Modified from Torres (2020)

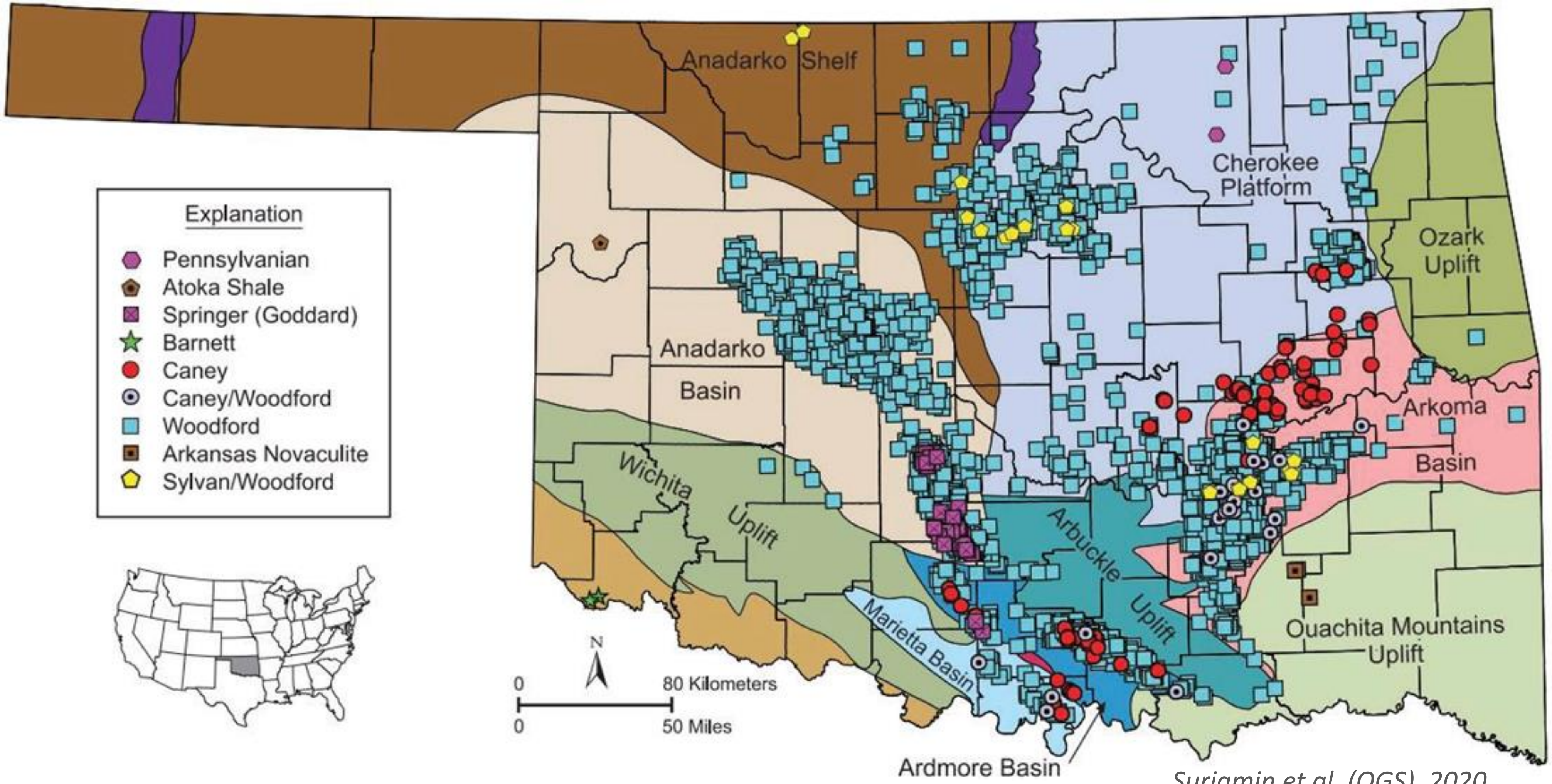
OUTLINE

- Intro to the Woodford Shale
  - Regional Geology
  - Depositional Model
- Woodford Facies
  - Facies (Outcrop/Core)
  - Fractures
  - Mechanostratigraphy
  - Geochemistry
  - RC and CQ model
- Chemostratigraphy and Sequence Stratigraphy
- Summary



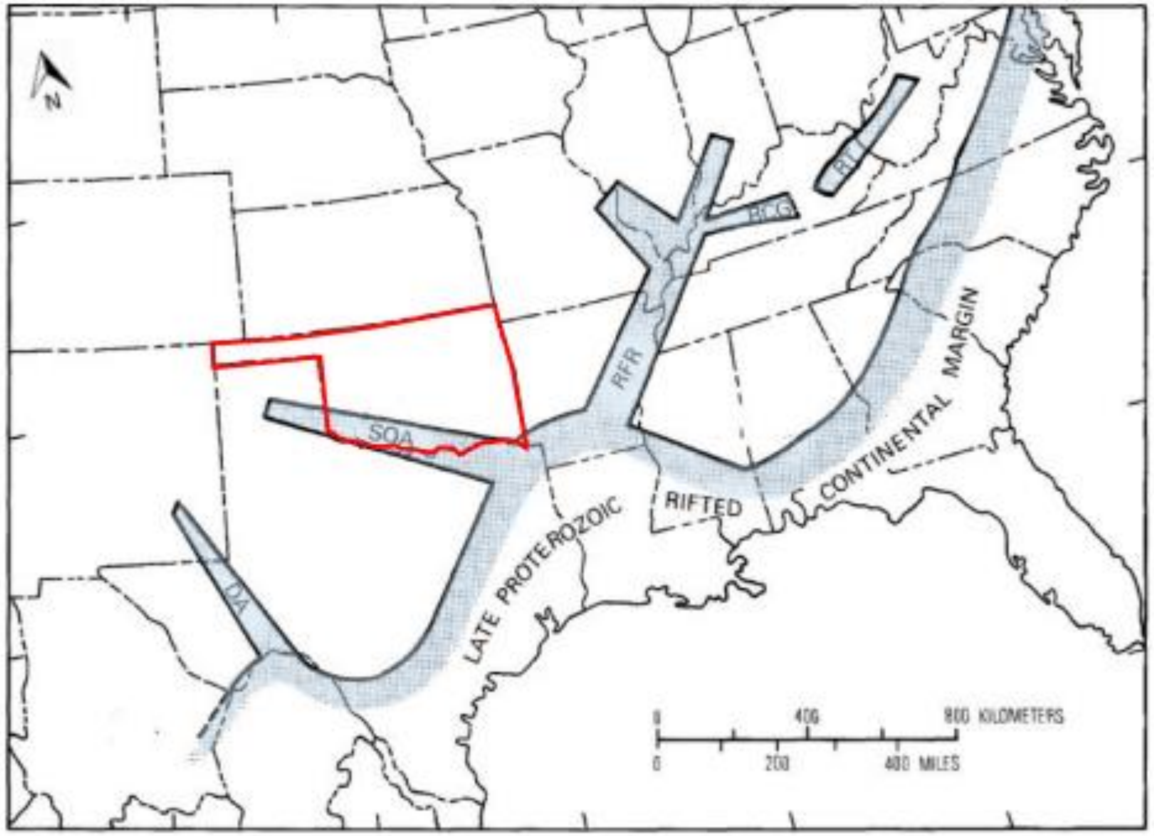
Galvis, 2017

King of Resource Shales in OK

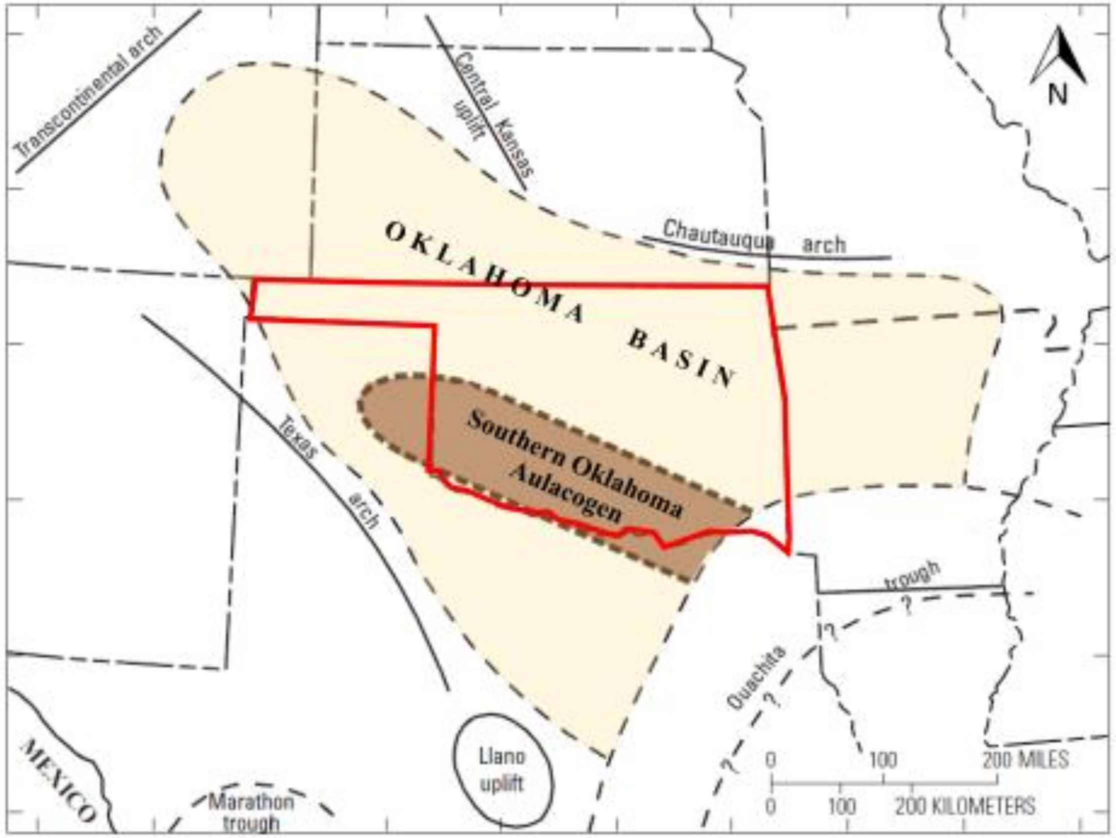


Suriamin et al. (OGS), 2020

Regional Geology

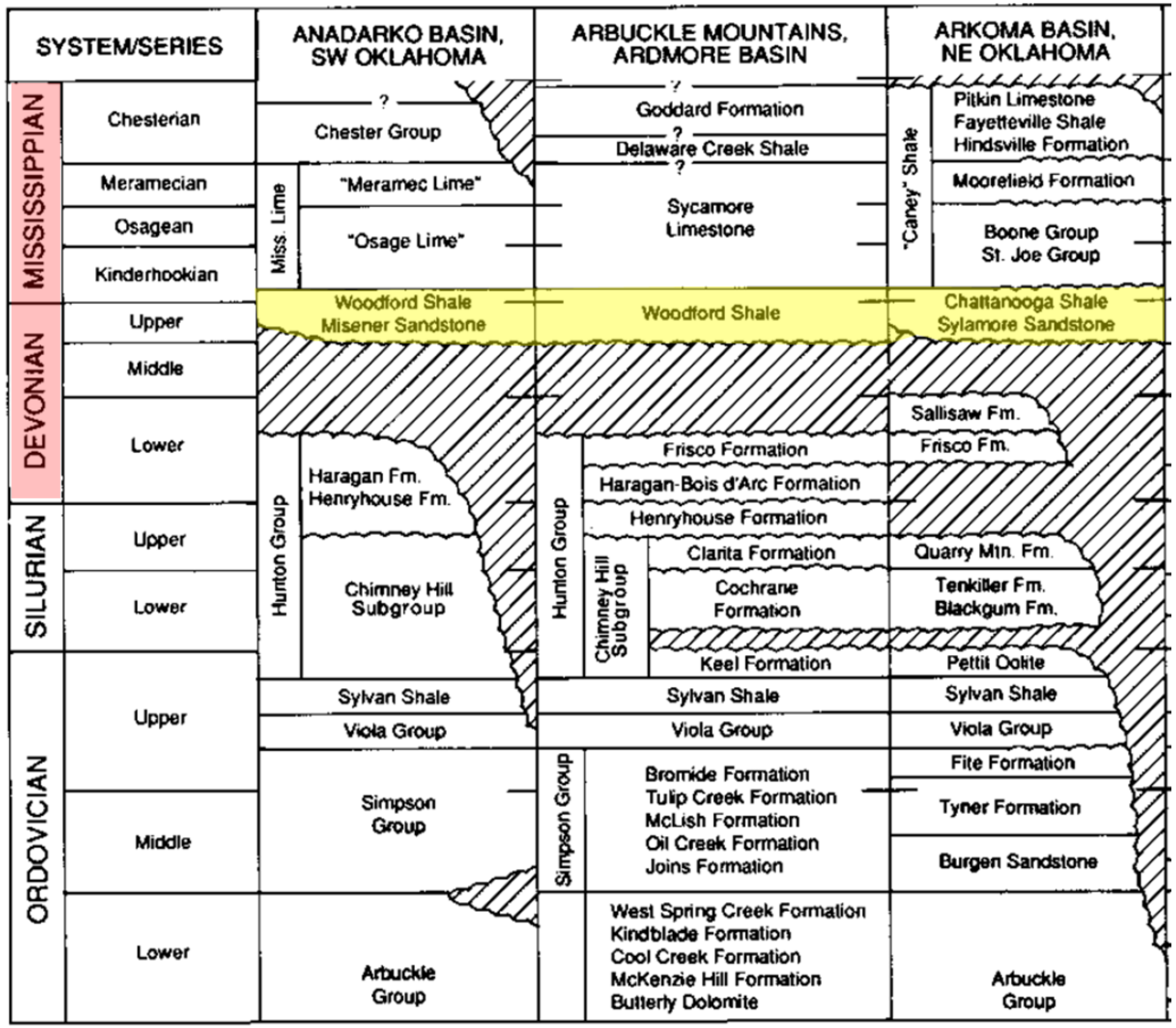


Becerra (2017) modified from Perry (1989) and Keller et al. (1983)



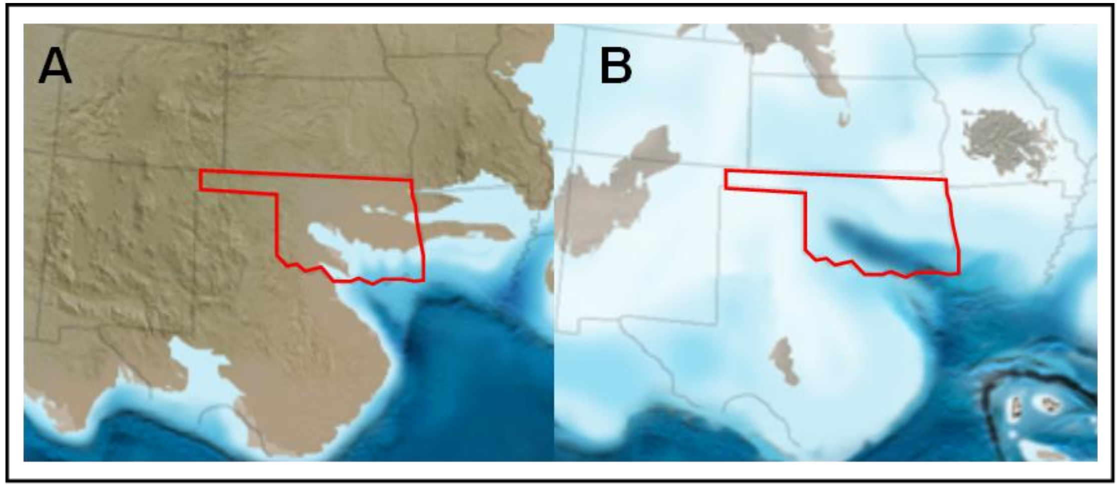
Becerra (2017) modified from Gaswirth and Higley (2014) and Johnson et al. (1989)

Stratigraphic Framework



(Modified from Johnson and Cardott, 1992)

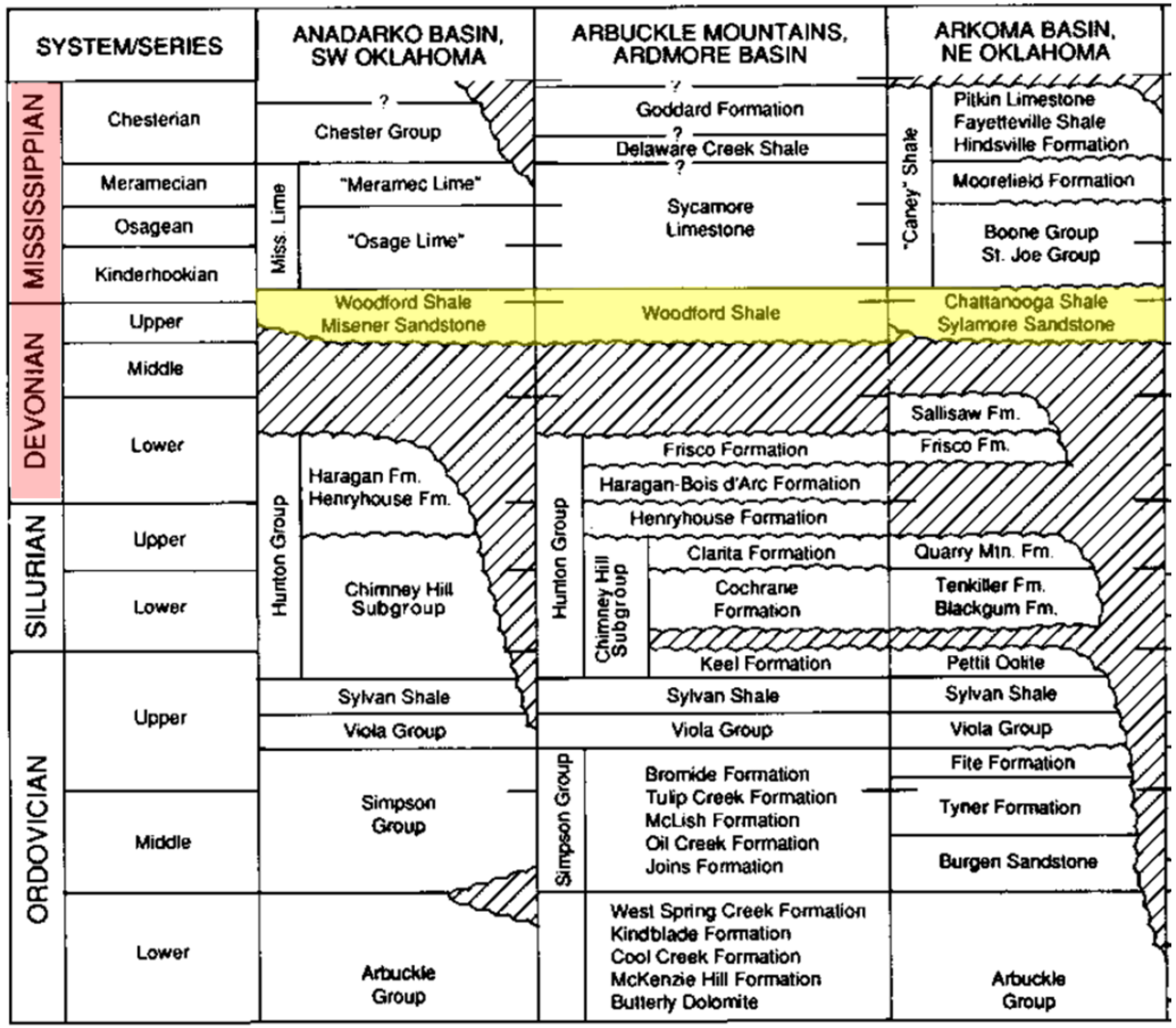
(Modified from Blakey, 2012 by McCullough, 2014)



A.) Onset of the Devonian B.) Onset of the Mississippian

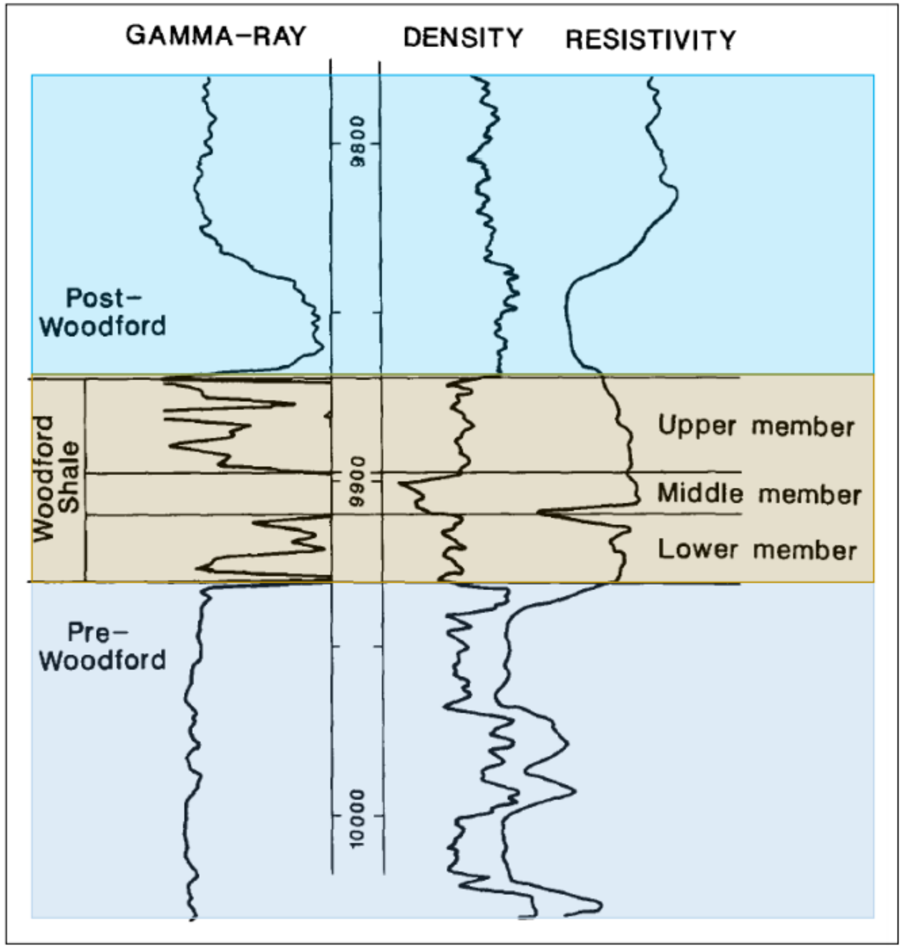
Woodford Shale was deposited during a regional transgression initiated in the Late Devonian that reached maximum flooding towards the Early Mississippian time

Woodford "Members"



(Modified from Johnson and Cardott, 1992)

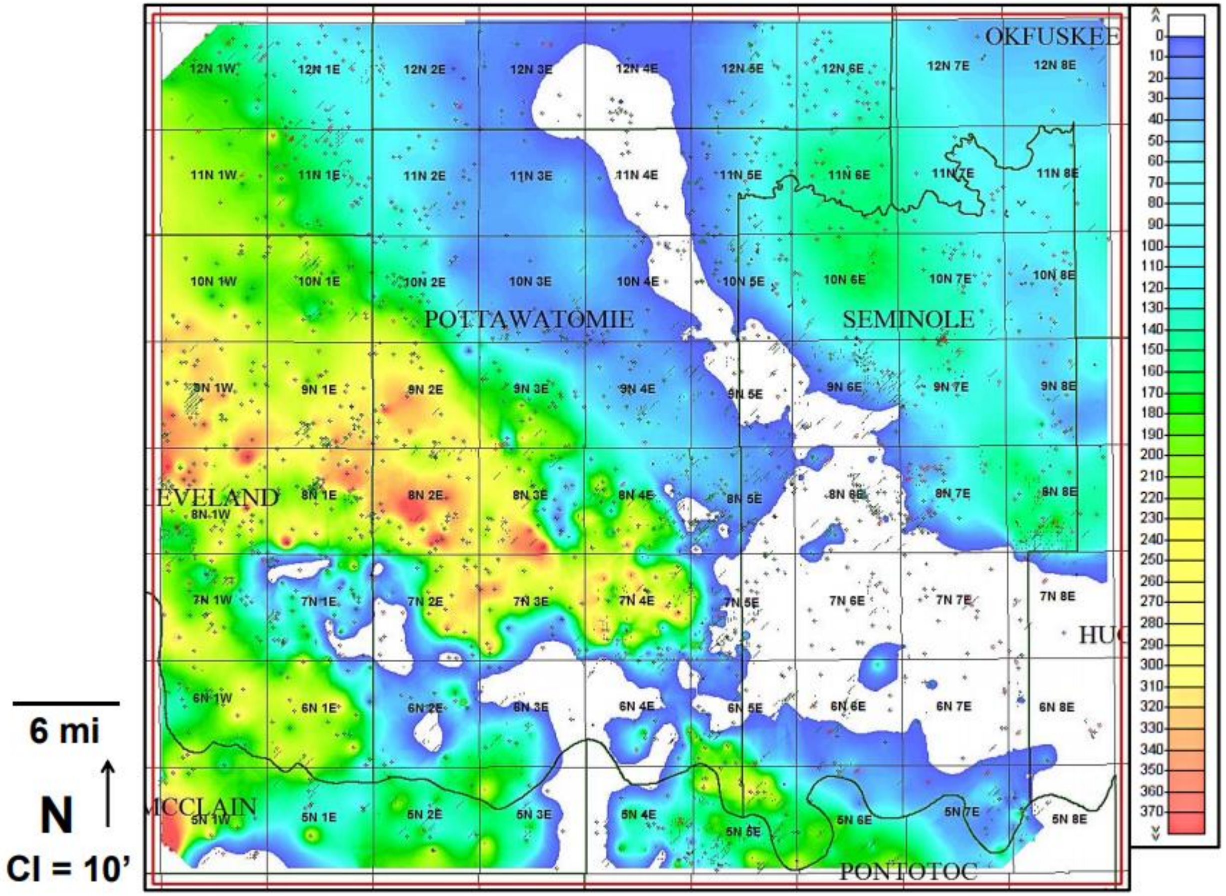
Unofficial Members



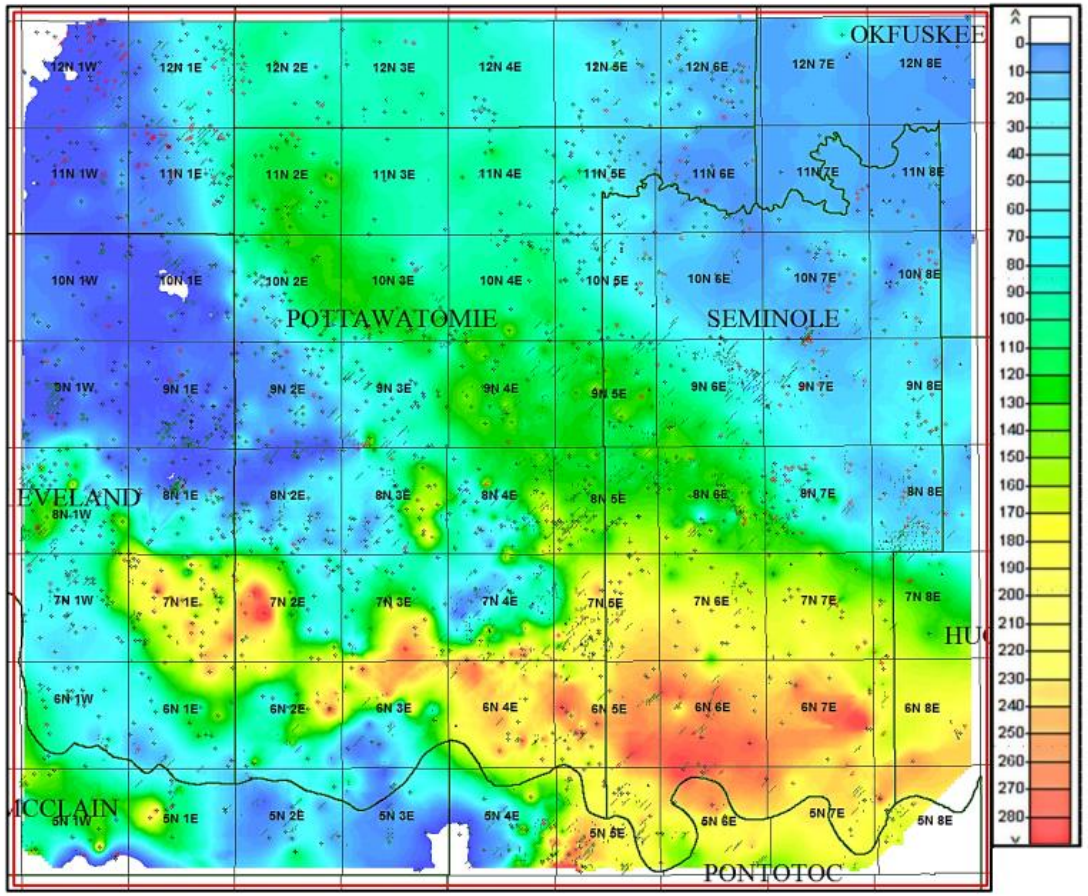
(Modified from Hester et al, 1990 by Becerra, 2017)

Hunton - Woodford Relationship

Hunton Group Isopach Map



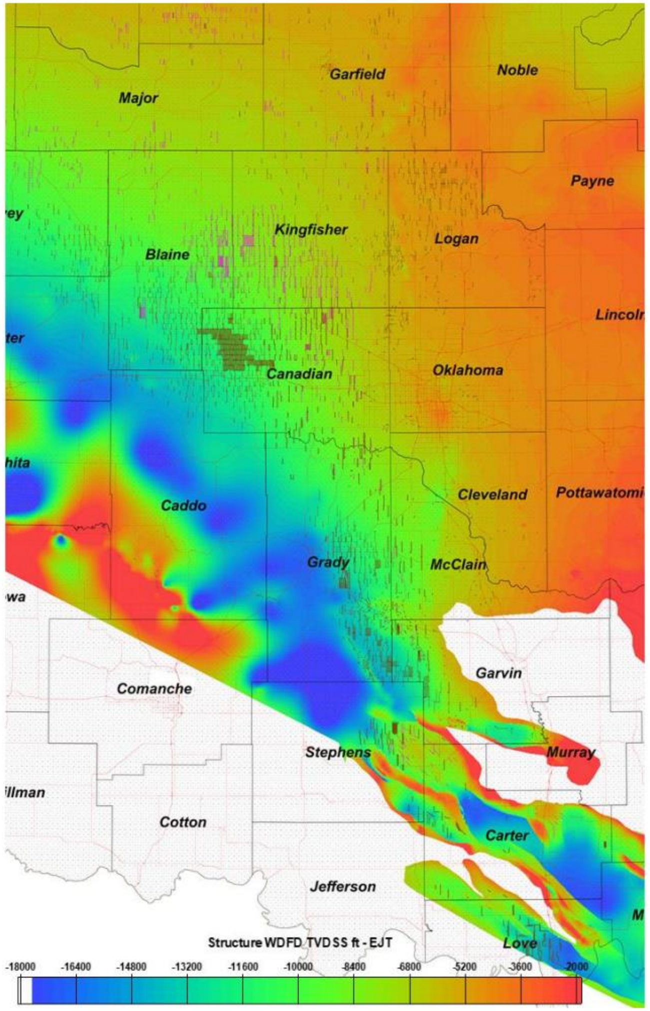
Woodford Shale Isopach Map



(*in* McCullough, 2014)

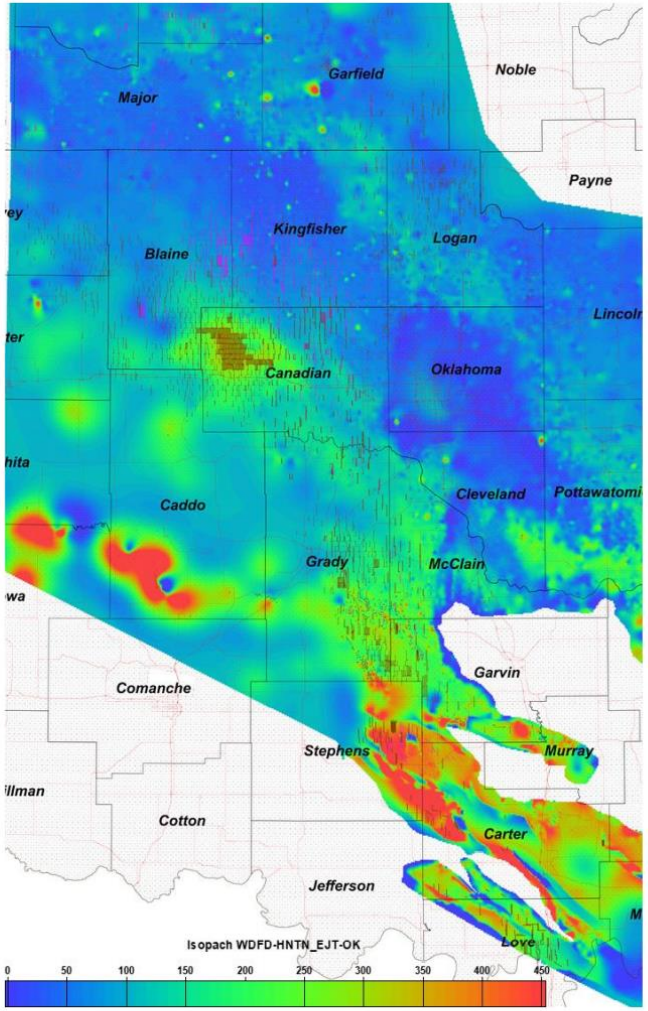
Woodford Regional Maps

Woodford Structure Map



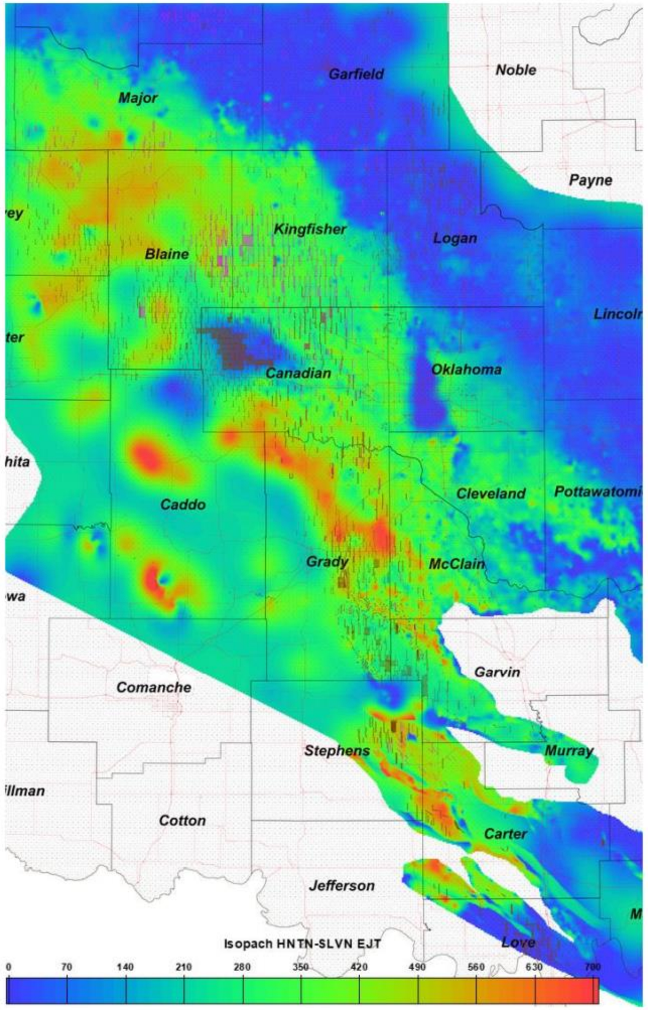
Torres, 2020

Woodford Thickness (Isochore) Map



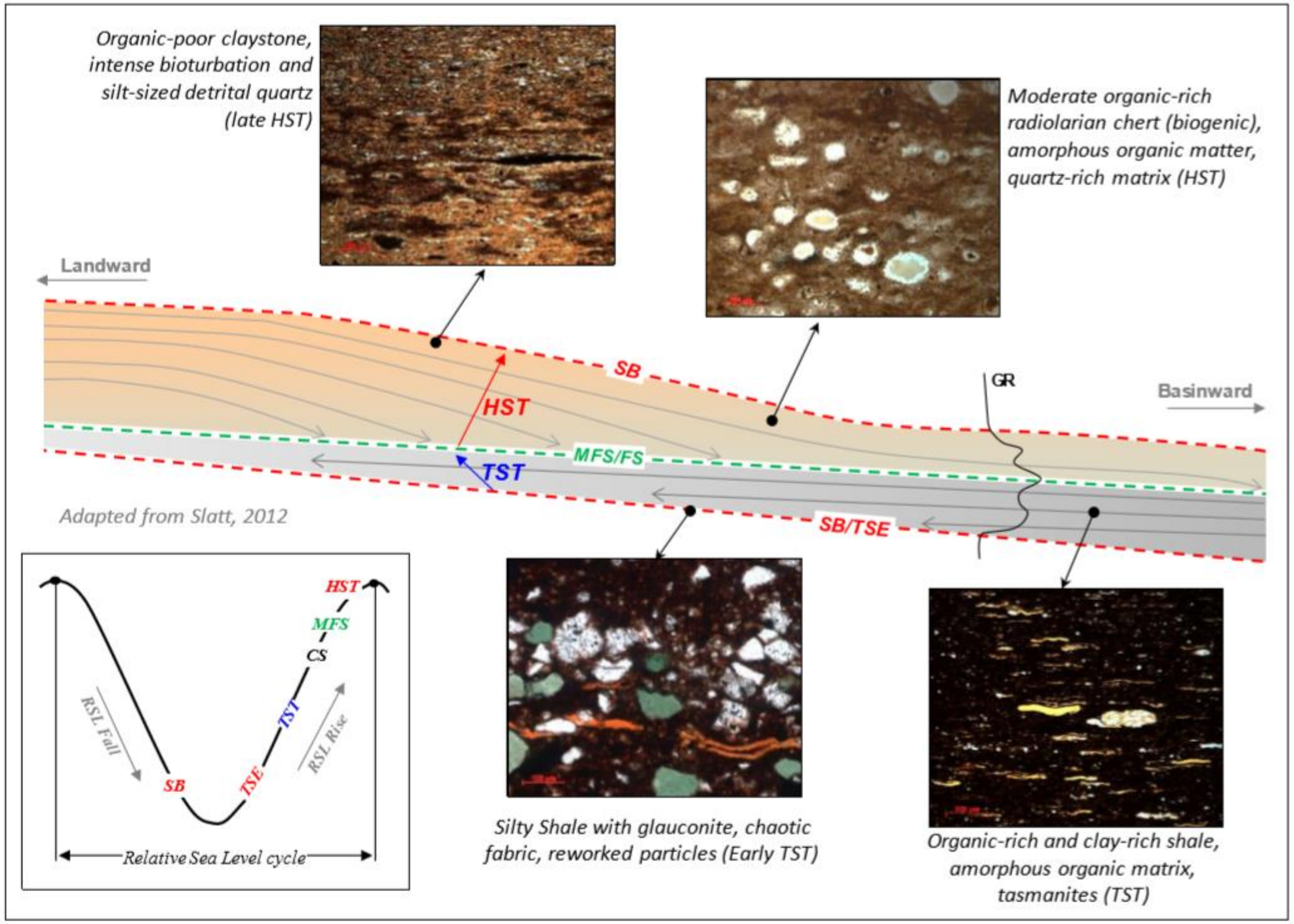
Torres, 2020

Hunton Thickness Map



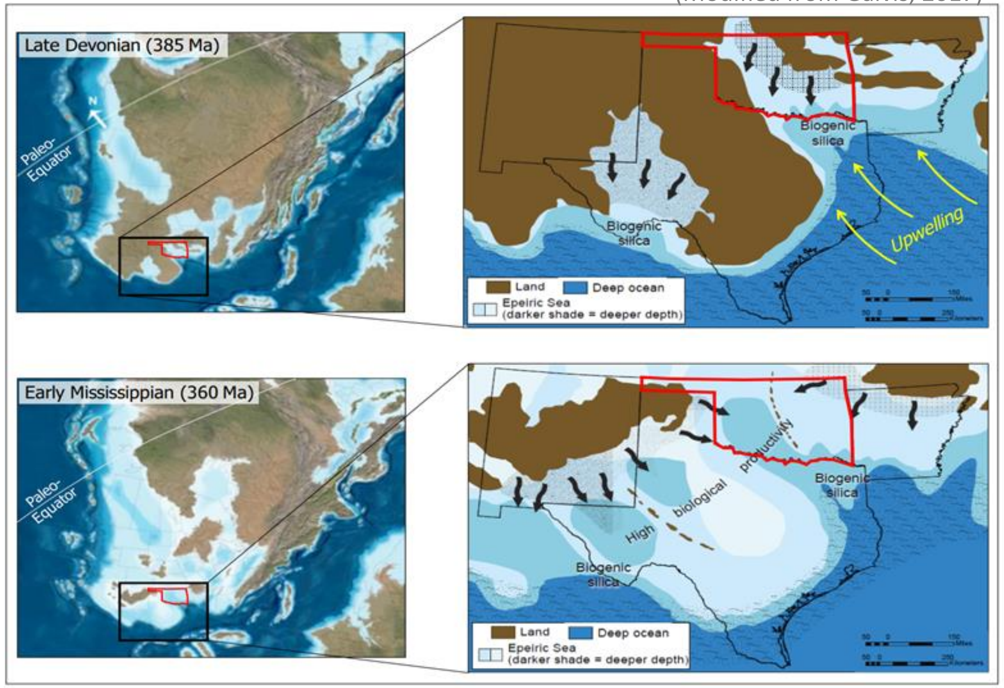
Torres, 2020

Depositional Model



(Modified from Galvis, 2017)

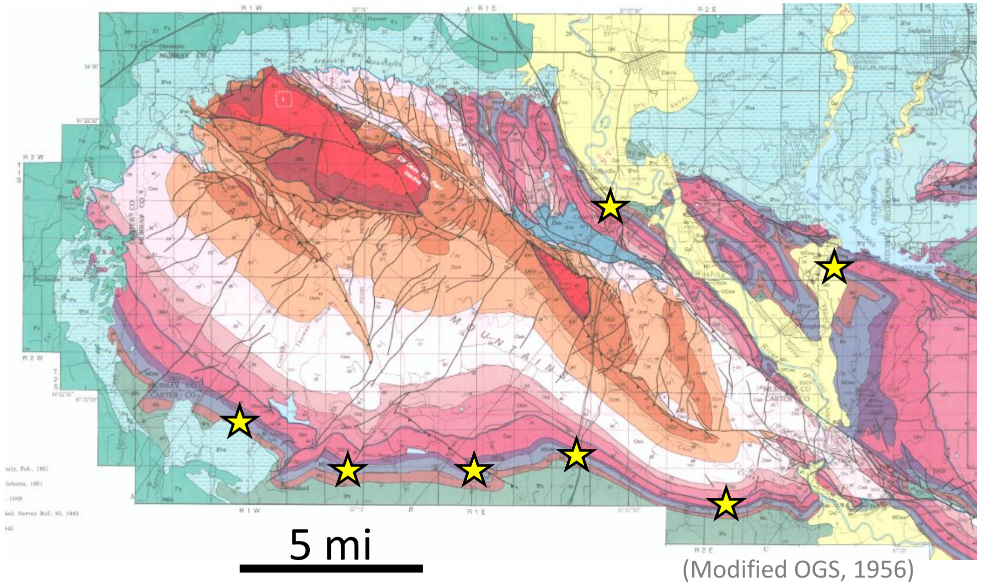
(Modified from Galvis, 2017)



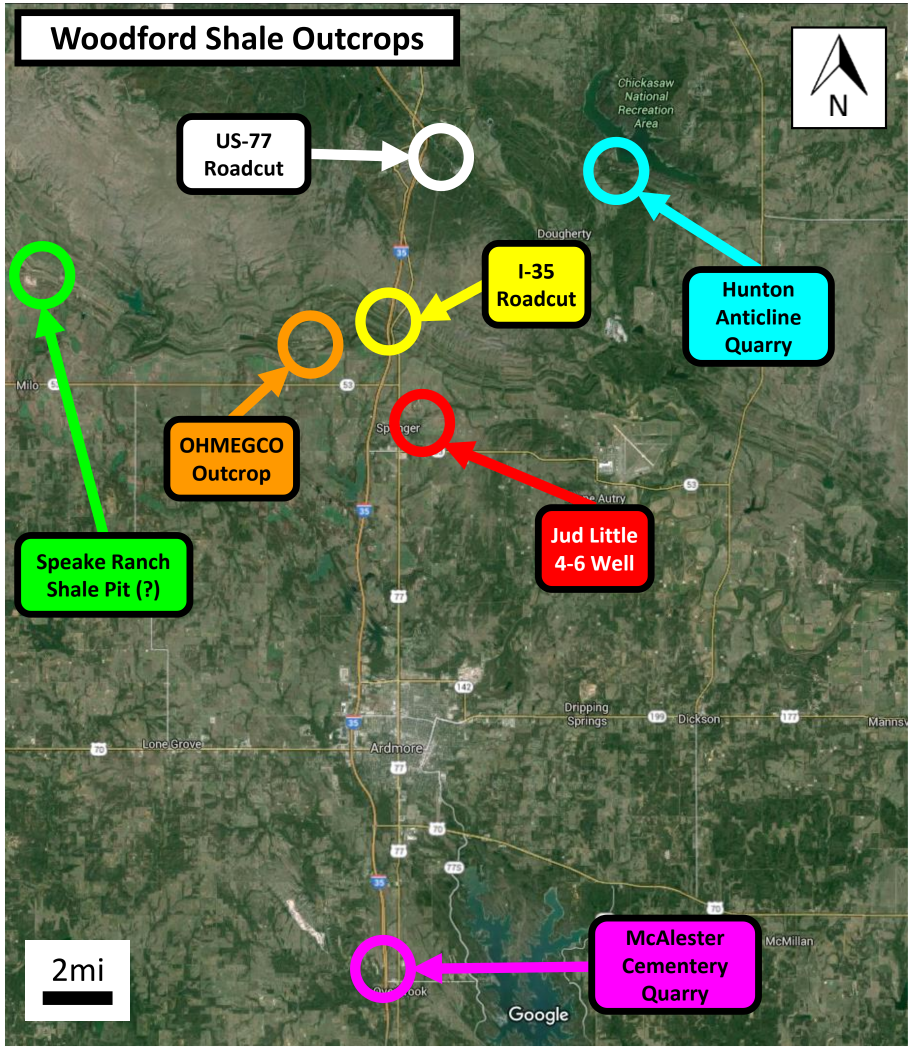
Regional paleogeography of North America's mid-continent region during the Late Devonian and Early Mississippian, showing the extensive epeiric sea covering most of the area of Oklahoma (modified from Comer, 2008).

Study Area - Outcrops

(Google, 2016)



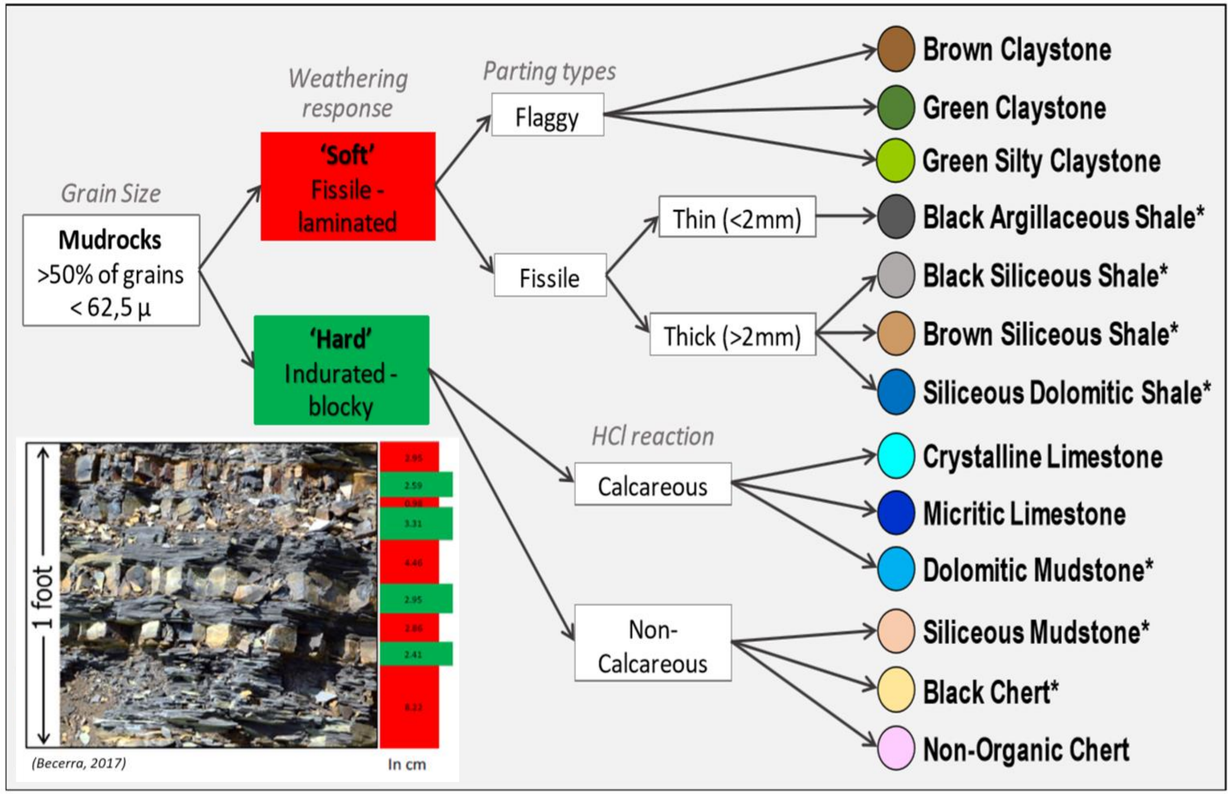
(Modified OGS, 1956)

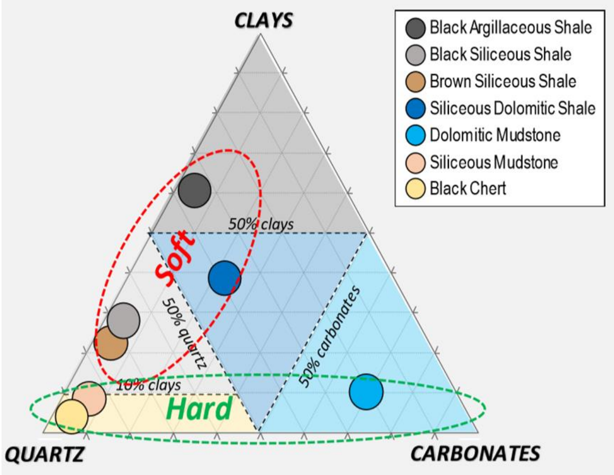


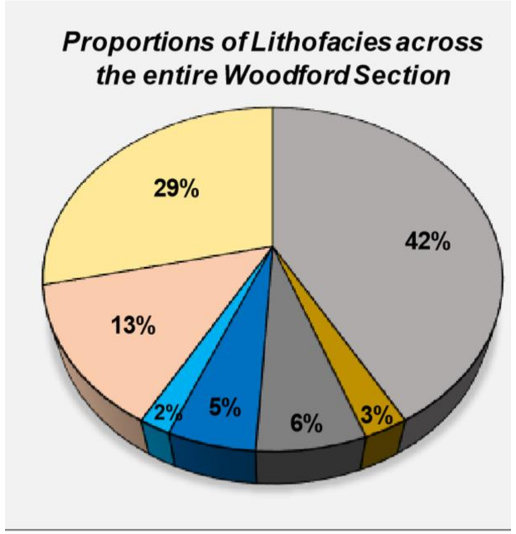
IRC (Brito), 2017

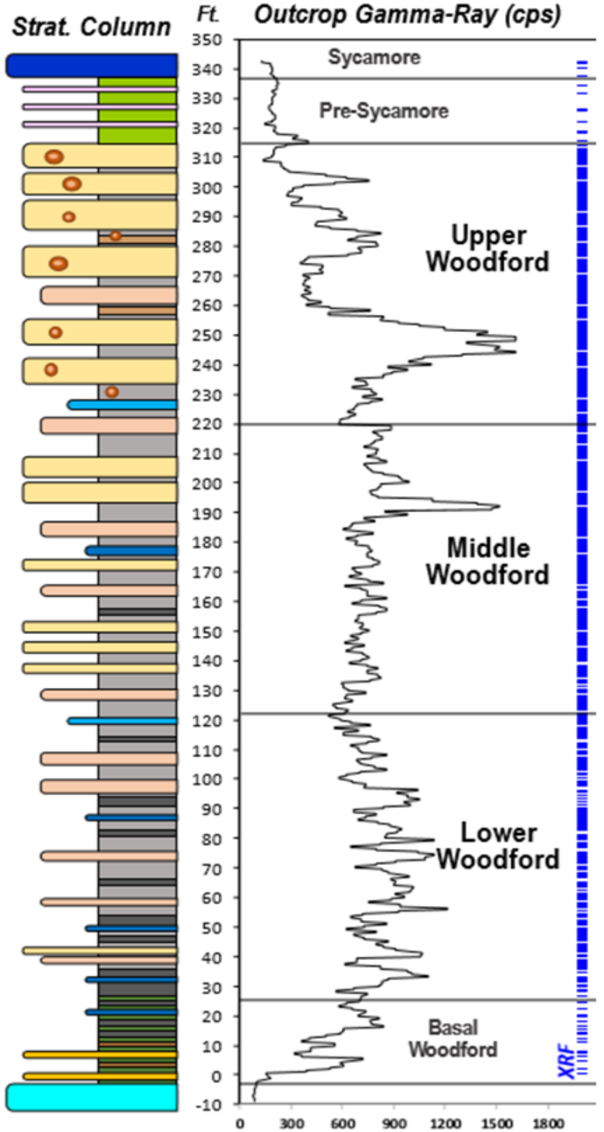
Outcrop Facies Classification

Lithofacies Classification of Speake Ranch Outcrop (Galvis, 2017)









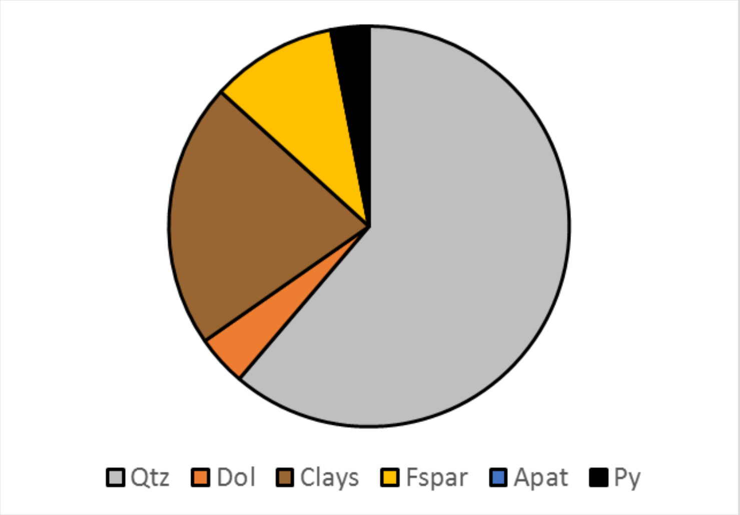
Galvis, 2017

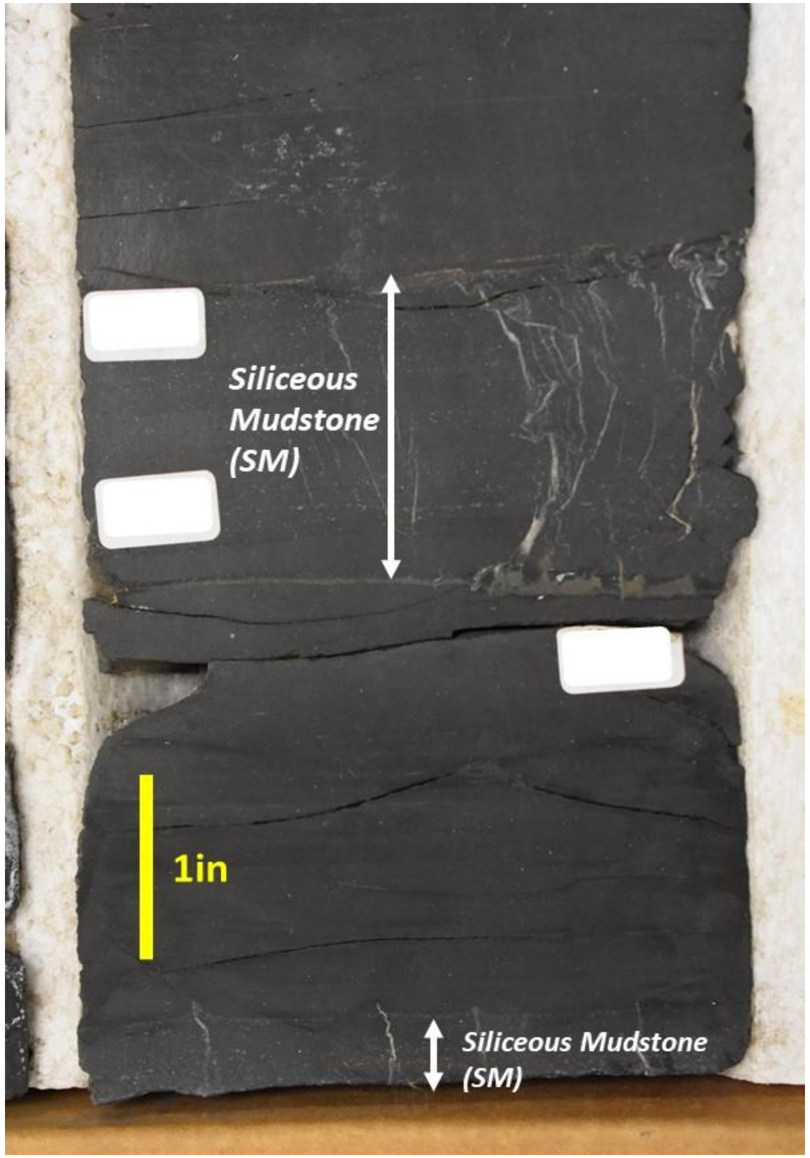
The most dominant facies from outcrop are the **Siliceous Shale**, **Siliceous Mudstone**, **Black Chert** and **Argillaceous Shale**.

Woodford Core Facies

Siliceous Mudstone (SM)

- **Color:** *Dark gray (N3) to Grayish Black (N2)*
- **Light Reflectivity:** *Medium*
- **Mineralogy:** *60% Quartz - 20% Clay*
- **TOC:** *4 – 6%*
- **Laminations:** *Subtle (aligned Radiolaria/Tas.)*
- **Fractures:** *Vertical – Mineralized (Compacted)*
- **HCl:** *No*

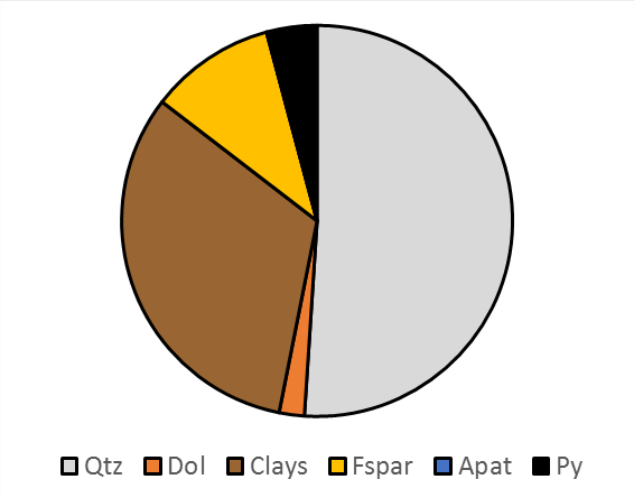


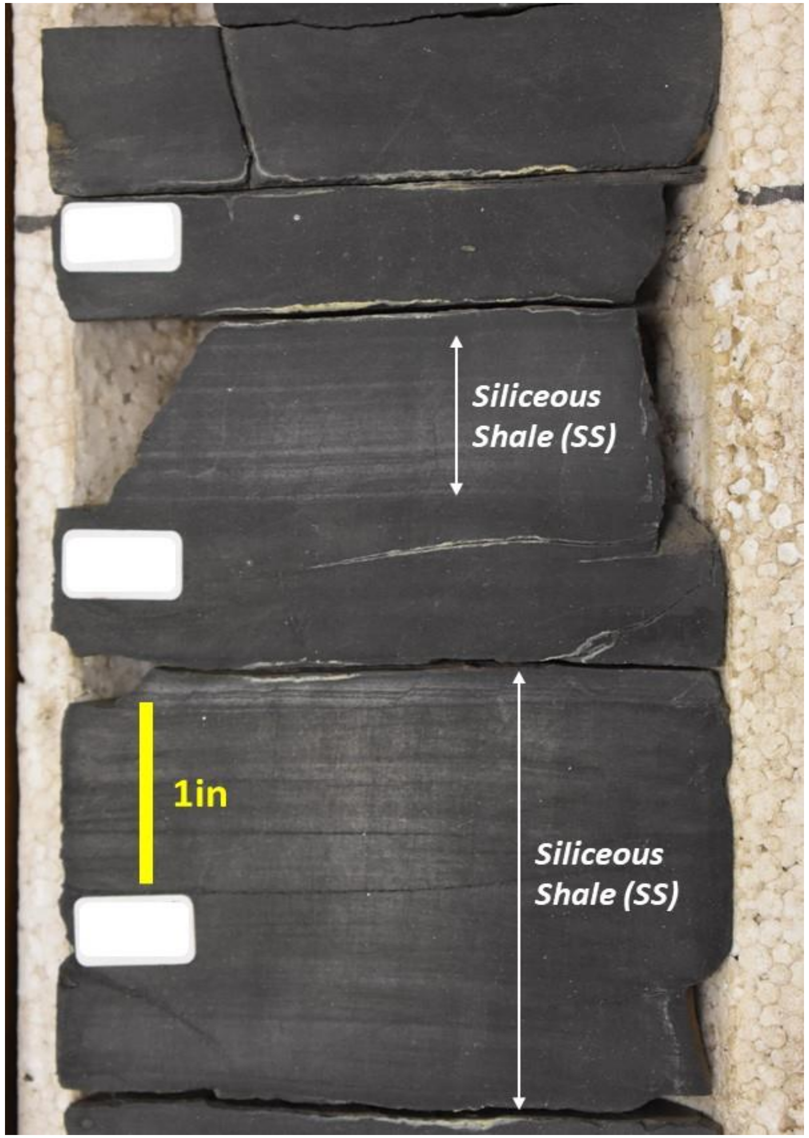


Brito, 2019

Siliceous Shale (SS)

- **Color:** *Brownish Black (5YR 2/1) to Grayish Black (N2)*
- **Light Reflectivity:** *Low*
- **Mineralogy:** *50% Quartz - 30% Clay*
- **TOC:** *6 - 8%*
- **Laminations:** *Well-defined*
- **Fractures:** Mostly HZ; some Vert.
- **HCl:** *No*

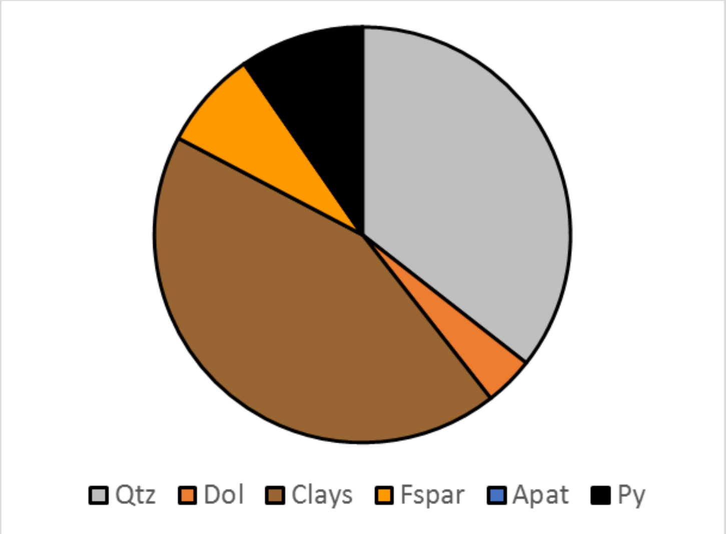


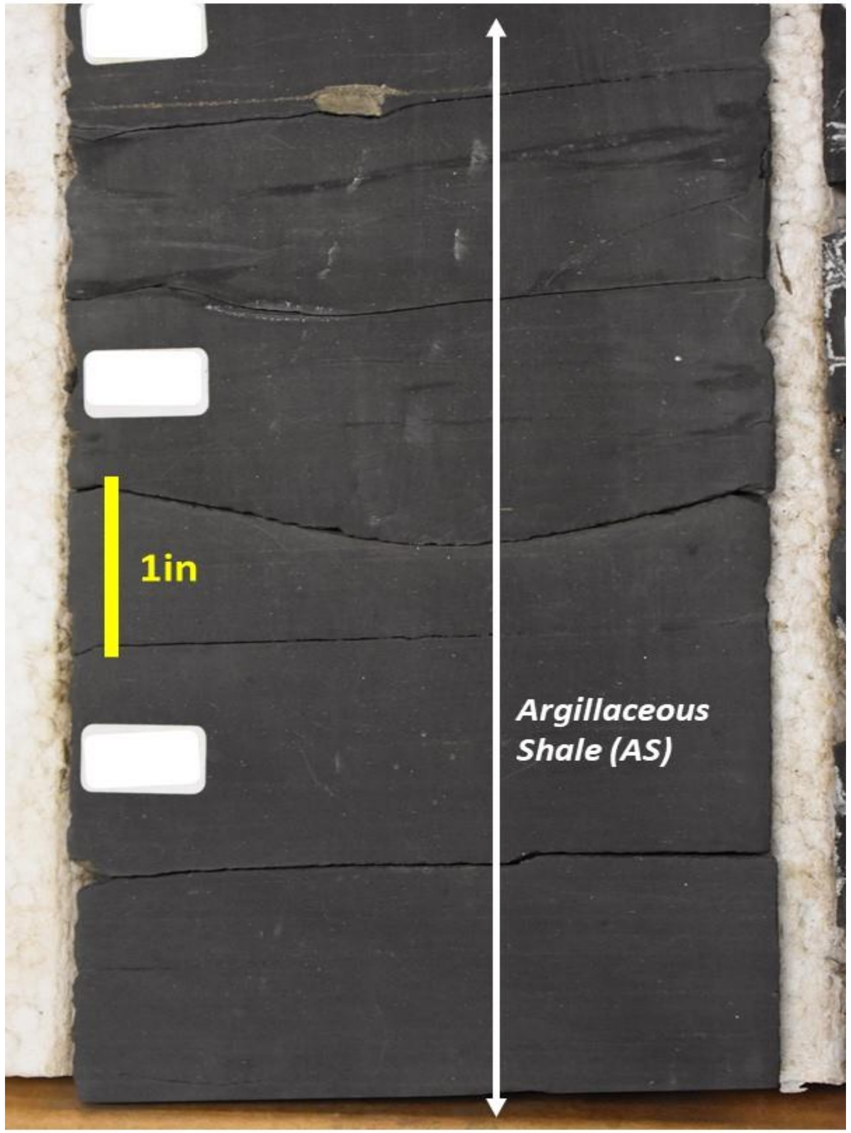


Brito, 2019

Argillaceous Shale (AS)

- **Color:** *Black (N1)*
- **Light Reflectivity:** *None*
- **Mineralogy:** *30% Quartz - 40% Clay*
- **TOC:** *7 – 10%*
- **Laminations:** Fine, Very *well-defined*
- **Fractures:** Horizontal
- **HCl:** *No*

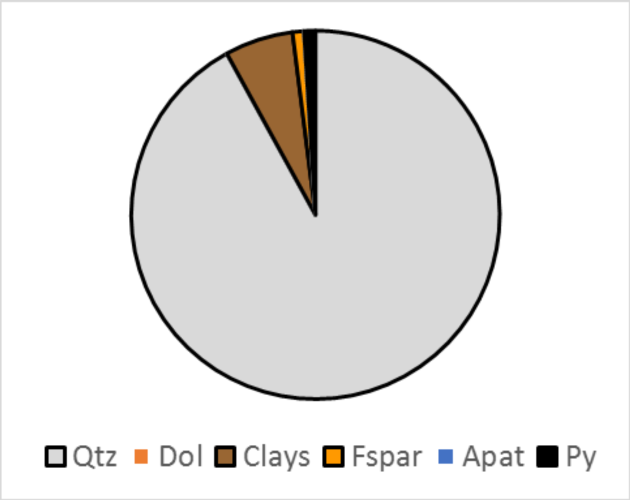


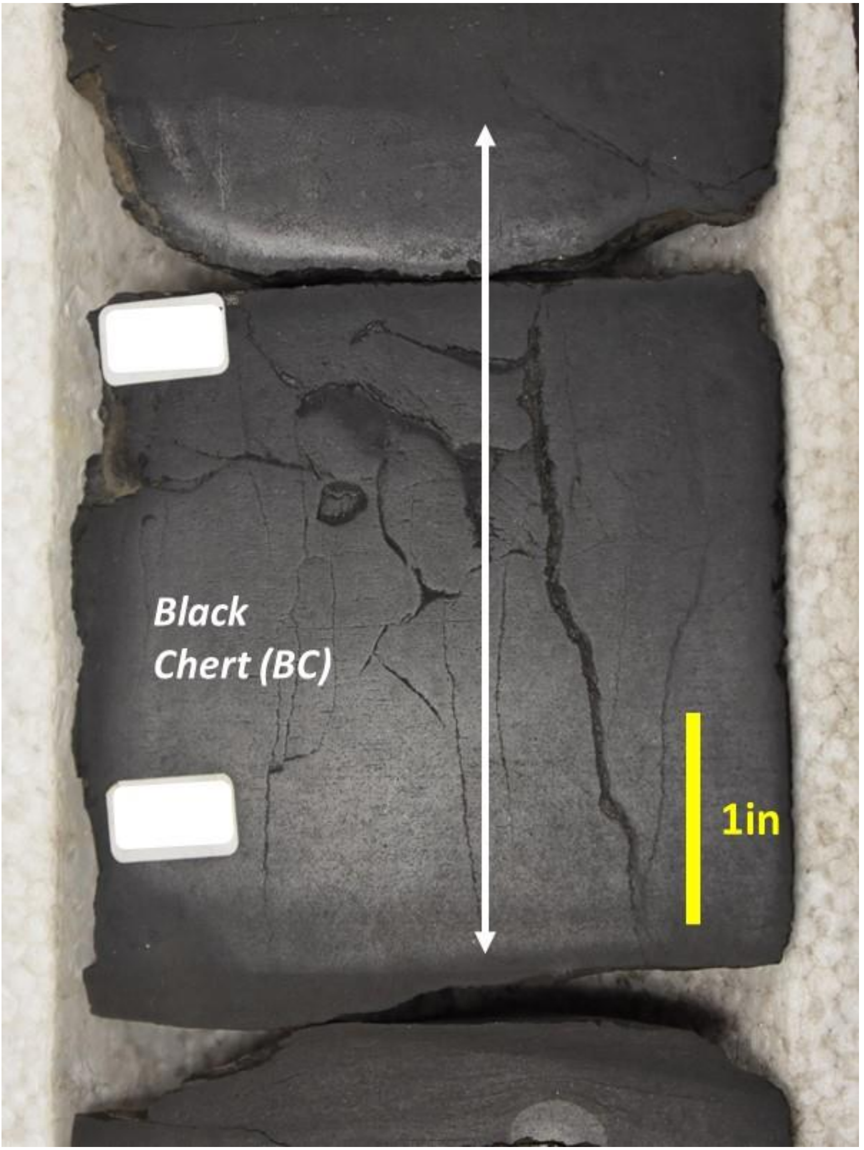


Brito, 2019

Black Chert (BC)

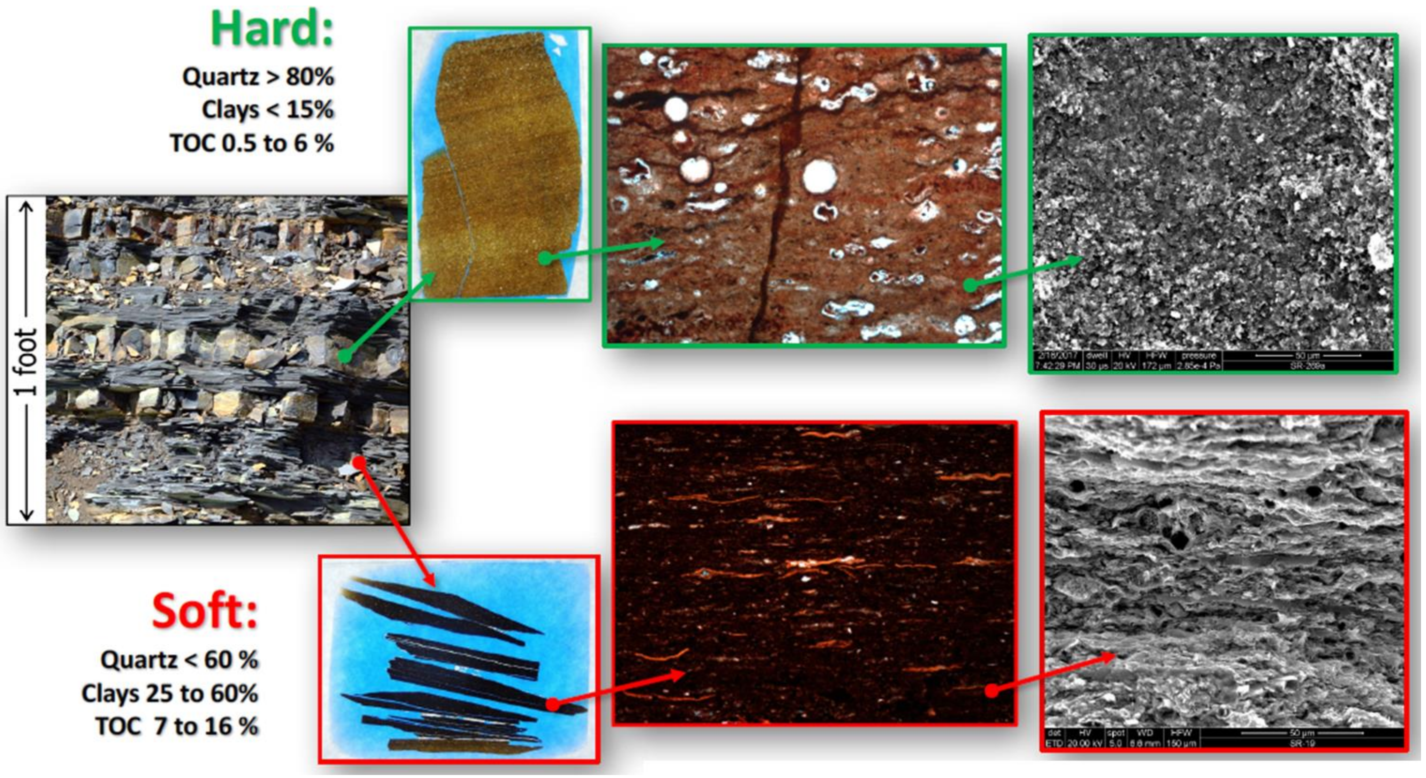
- **Color:** *Dark Gray (N3) to Black (N1)*
- **Light Reflectivity:** *High*
- **Mineralogy:** *90% Quartz - <10% Clay*
- **TOC:** *2 – 4%*
- **Laminations:** Few to none
- **Fractures:** Vertical
- **HCl:** *No*

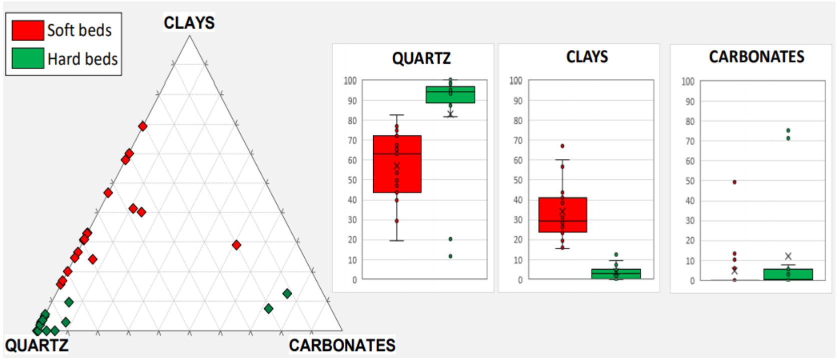




Brito, 2019

Hard (Brittle) – Soft (Ductile)

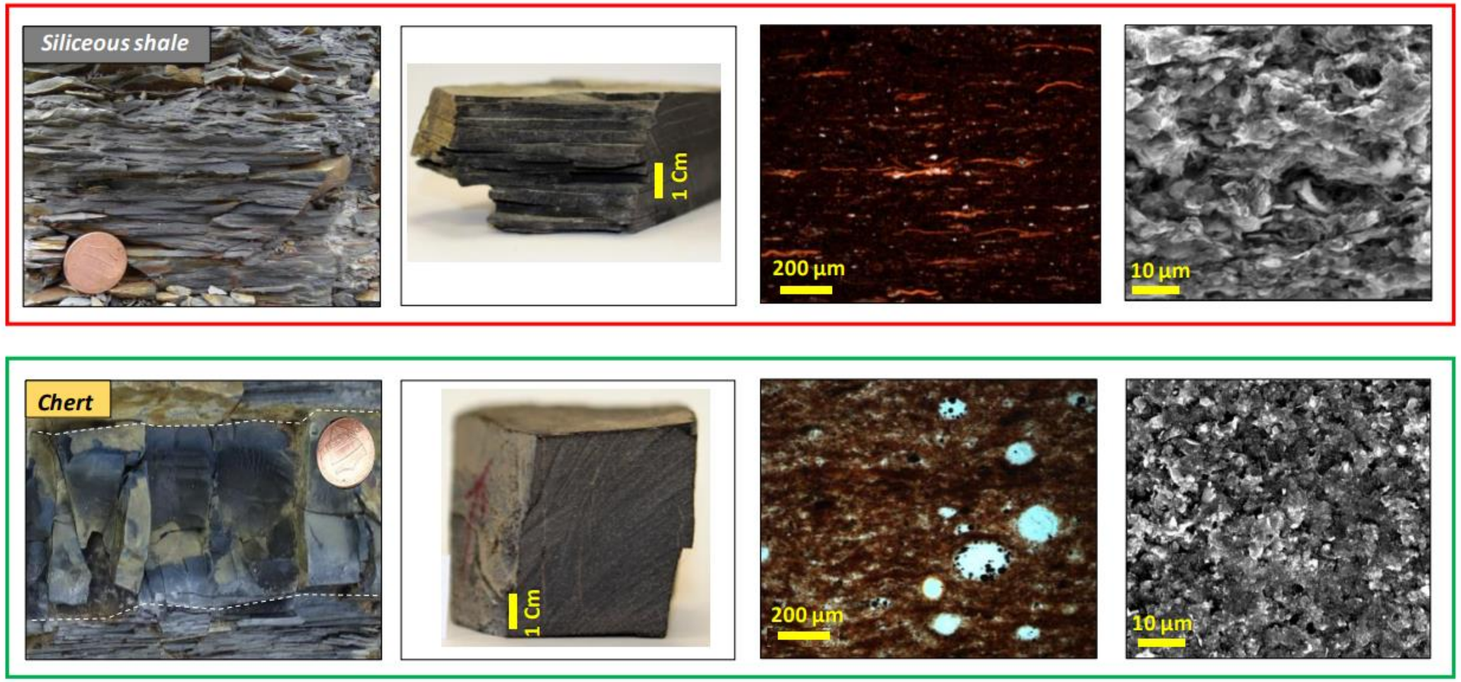




(Becerra, 2017; Galvis, 2017)

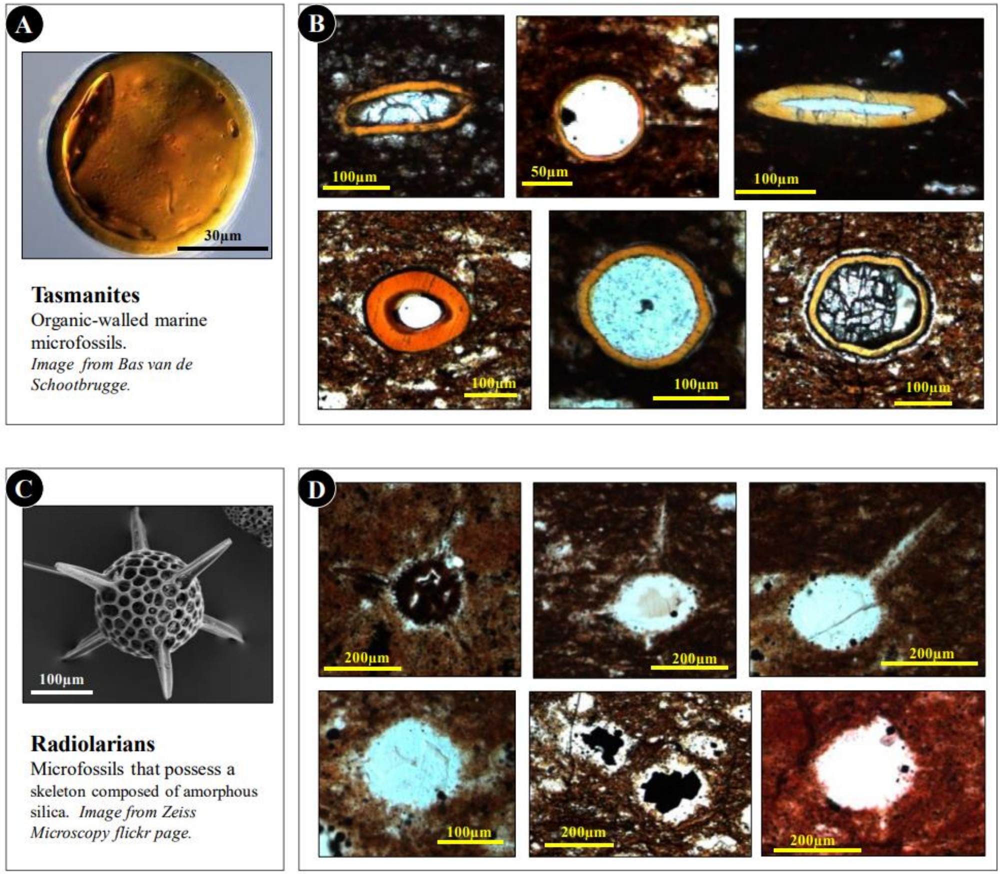
Becerra, 2017 courtesy of Brito

Hard (Brittle) – Soft (Ductile)



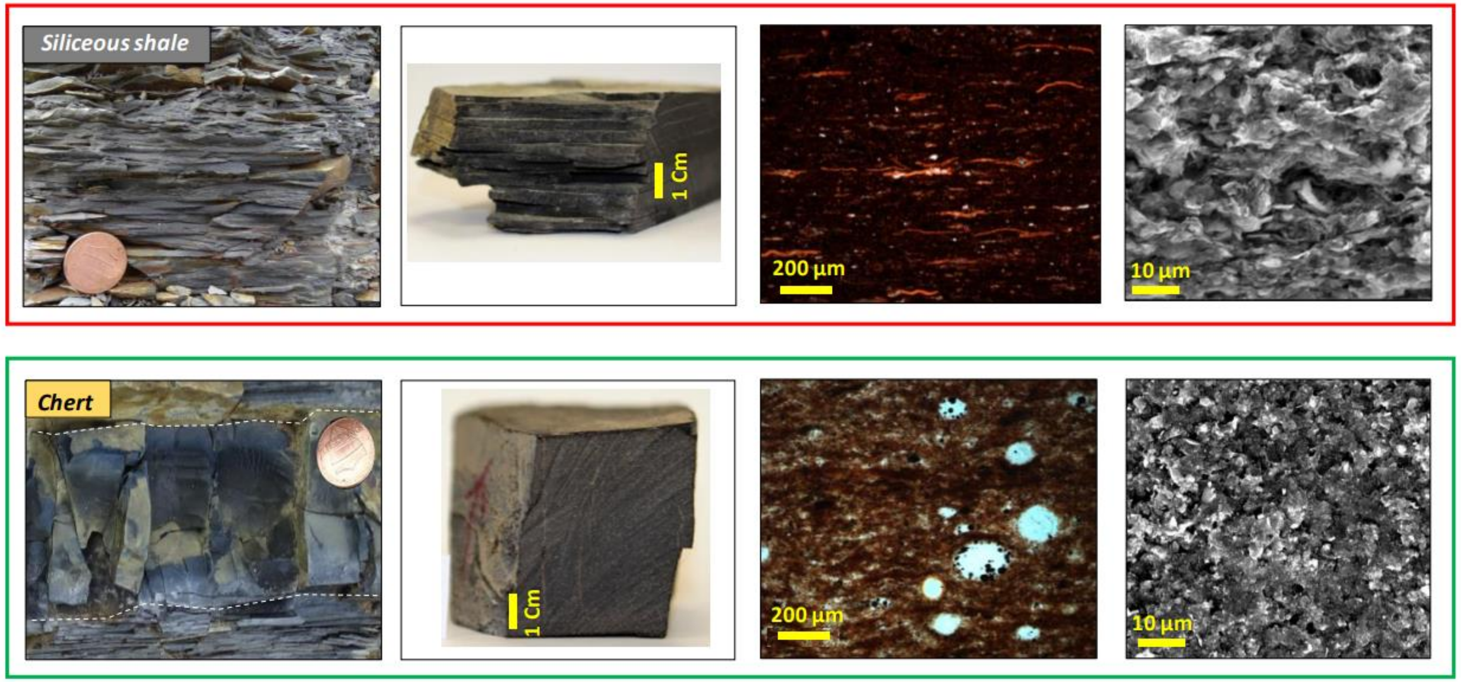
Weathering Response	Lithofacies	Physical Apparance	Microfabric	Fossils
Soft	Siliceous Shales	Fissile, Laminated	Subtle preferred parallel orientation	Flattened *tasmanites*
Hard	Chert	Hard, massive	Random oriented microcrystalline aggregates	Well-preserved, rounded silicified radiolarians and *tasmanites*

Galvis, 2017
Becerra, 2017



Galvis, 2017

Hard (Brittle) – Soft (Ductile)



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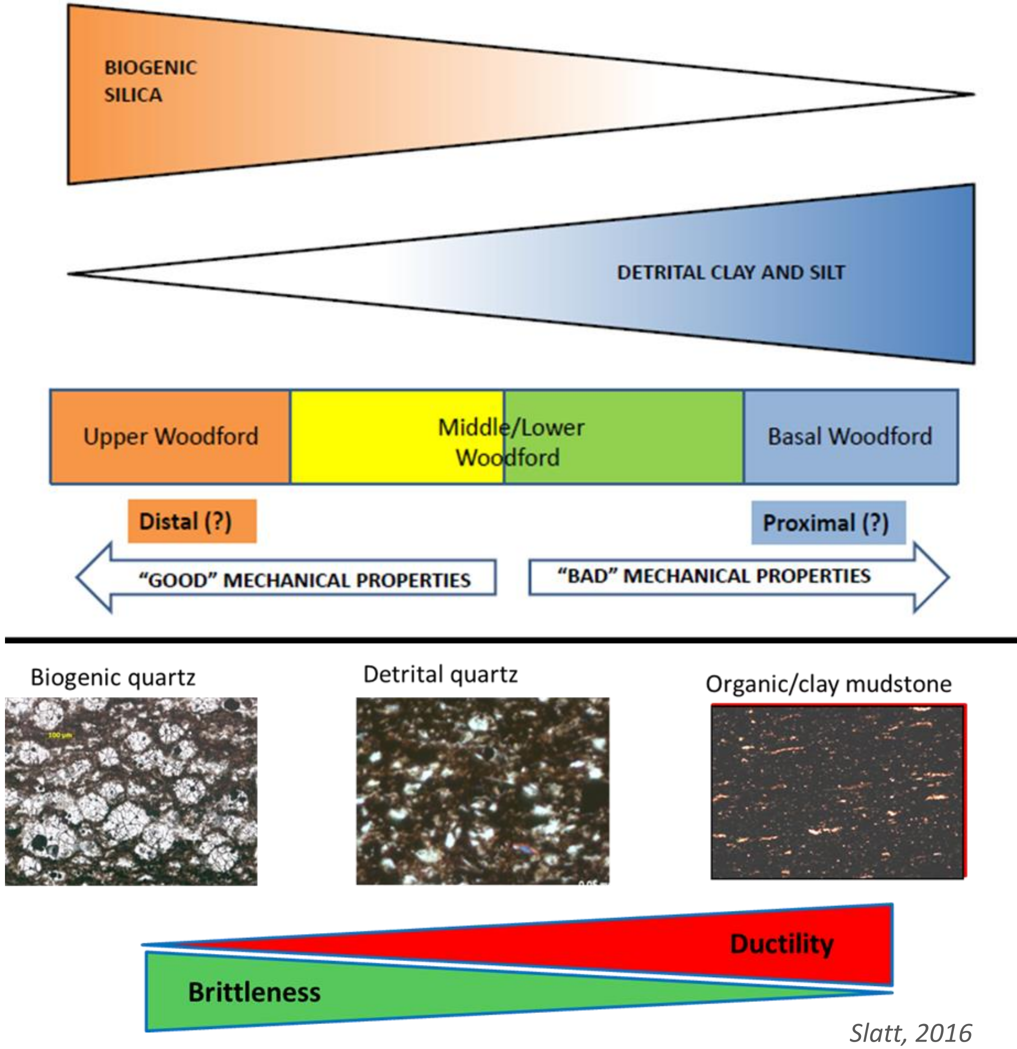
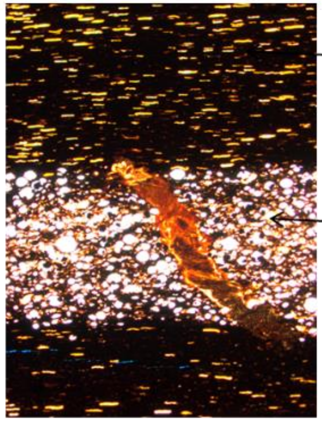
Galvis, 2017
Becerra, 2017

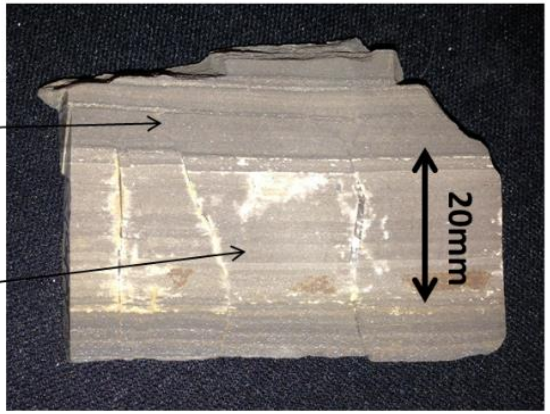


Slatt, 2016

Fracture Propagation

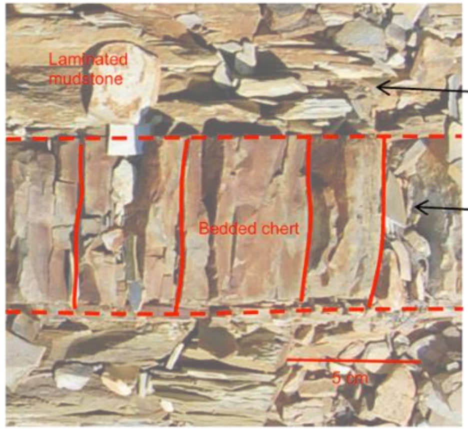
Natural Fractures, Woodford Shale: The effect of lithology





Mudstone

Chert

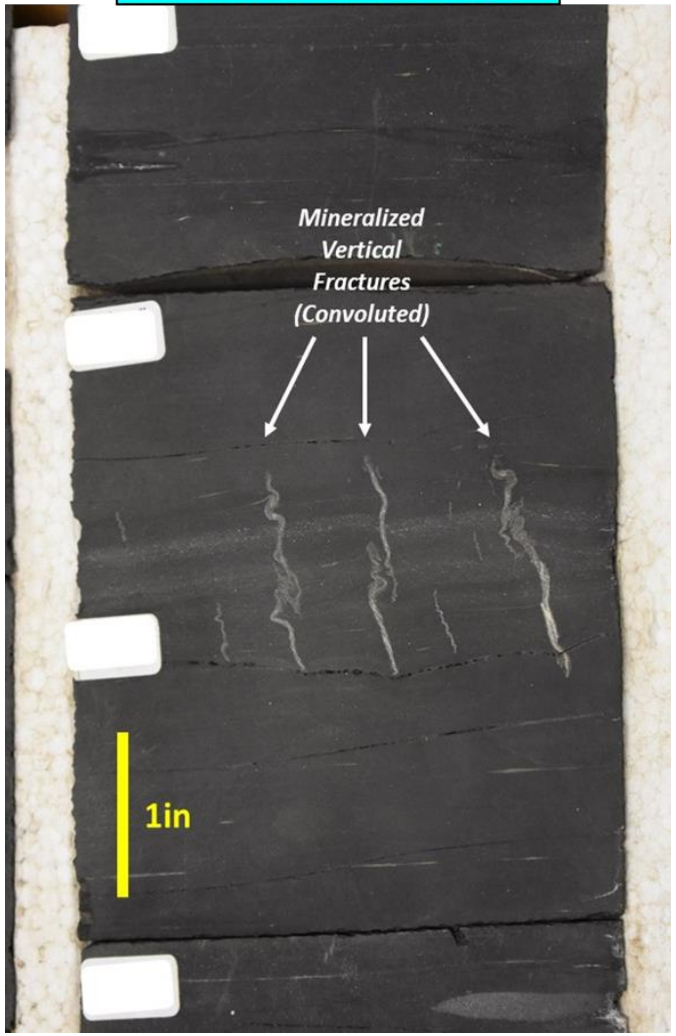


Mudstone

Chert

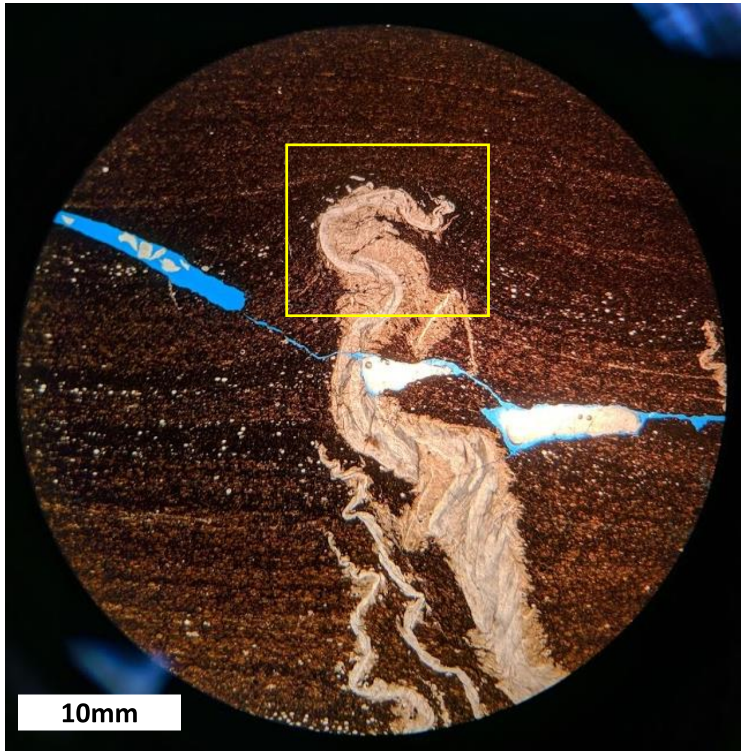
"Brittle-Ductile Couplets"
(Slatt and Abousleiman, 2011)

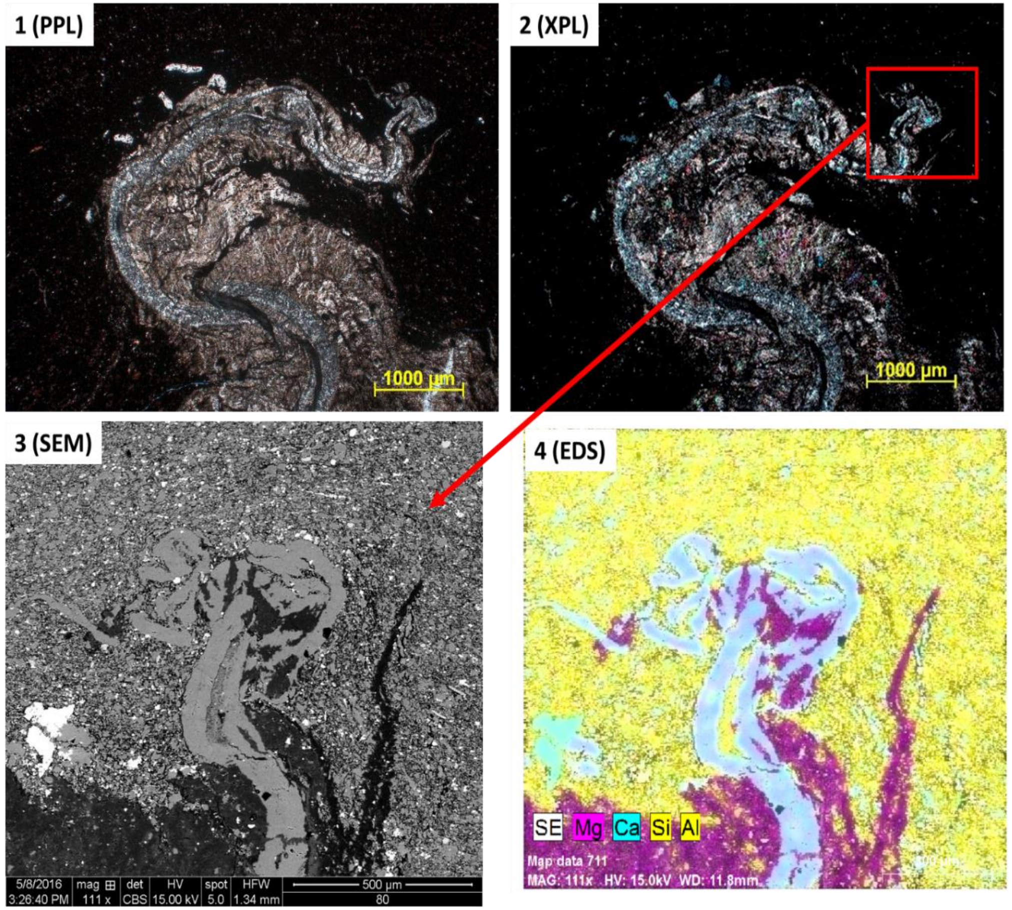
Vertical Fractures



Brito, 2019

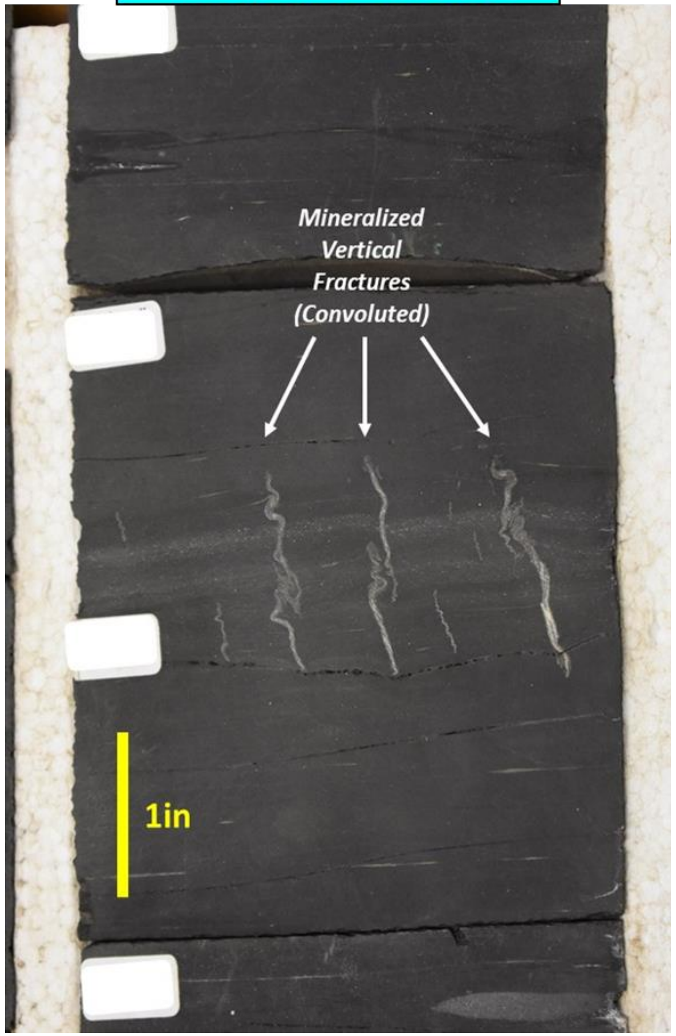
Woodford Fractures





Brito, 2019

Vertical Fractures



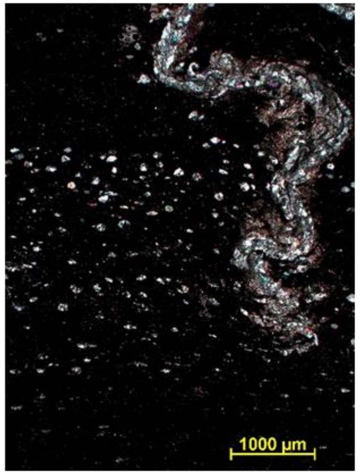
Brito, 2019

Fractures that are formed/healed before compaction.
Then after compaction they get convoluted.

Matrix effect in Fractures

Organic/Radiolarian Rich (Good fracture propagation, good presence of organic less silica inside radiolarians, but also pyrite that fill in the pores affect negatively)

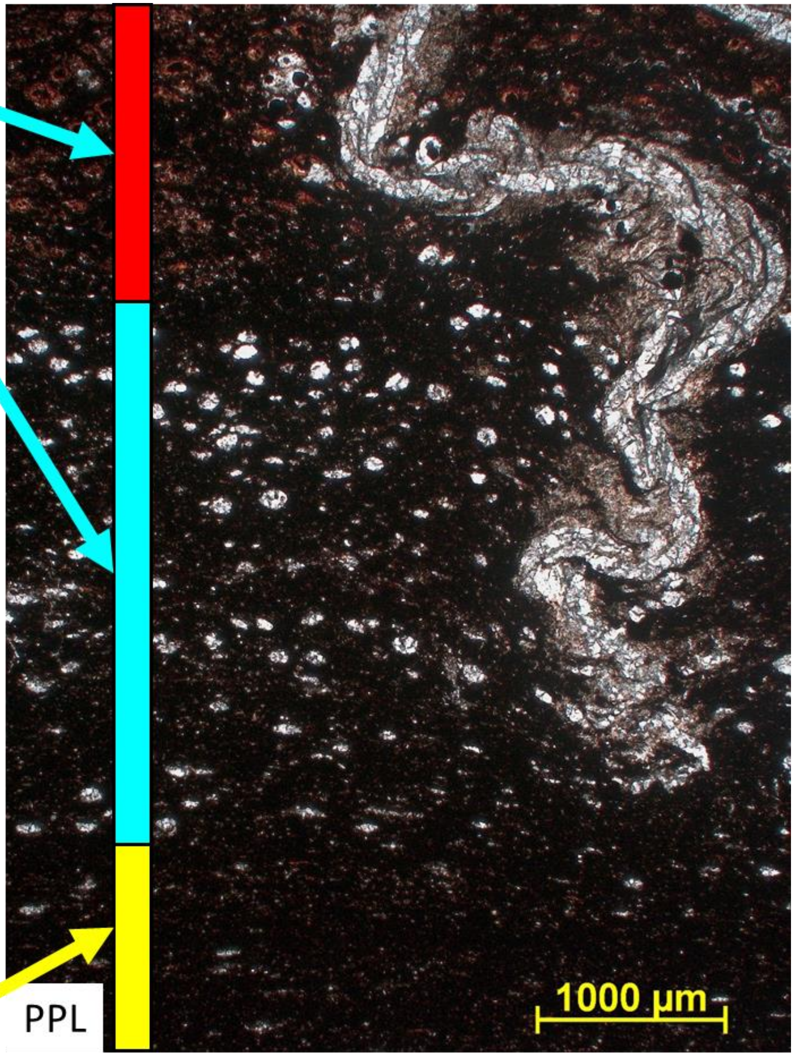
Silica Rich (Good fracture propagation and more convoluted)



XPL

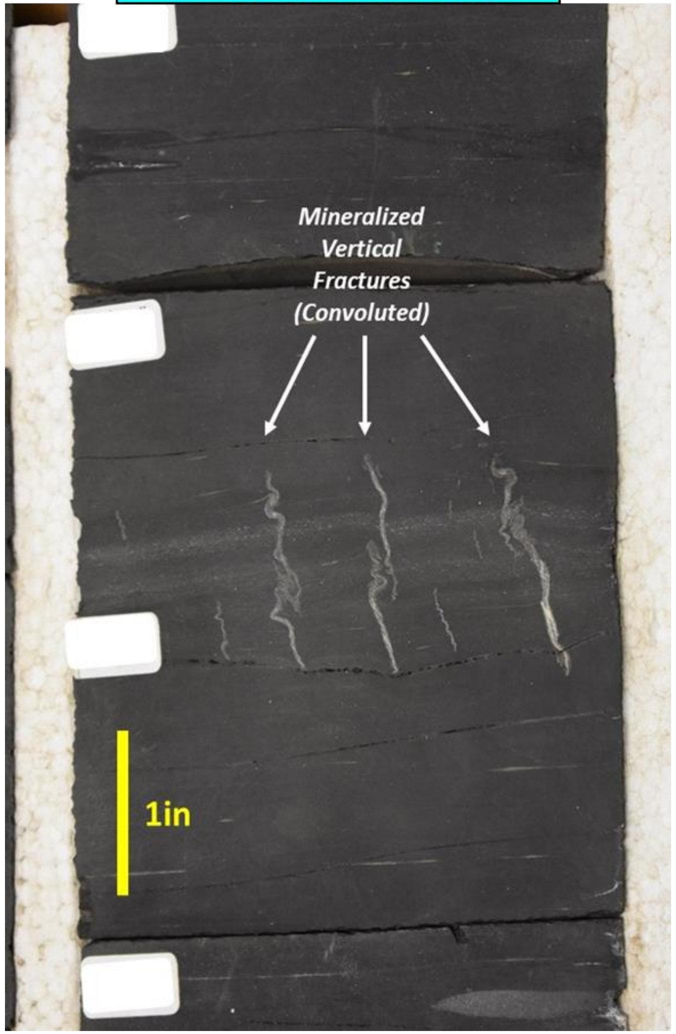
RL

Clay rich matrix (Limit fractures propagation)



Brito, 2019

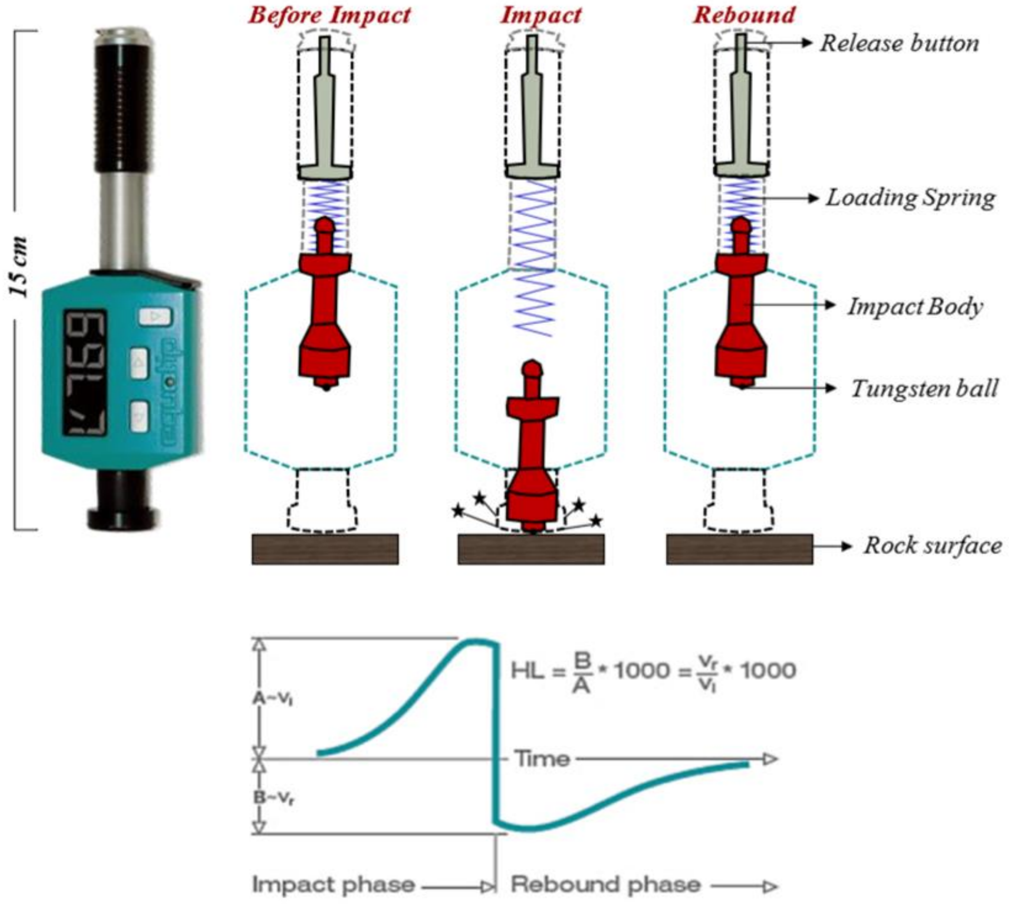
Vertical Fractures



Brito, 2019

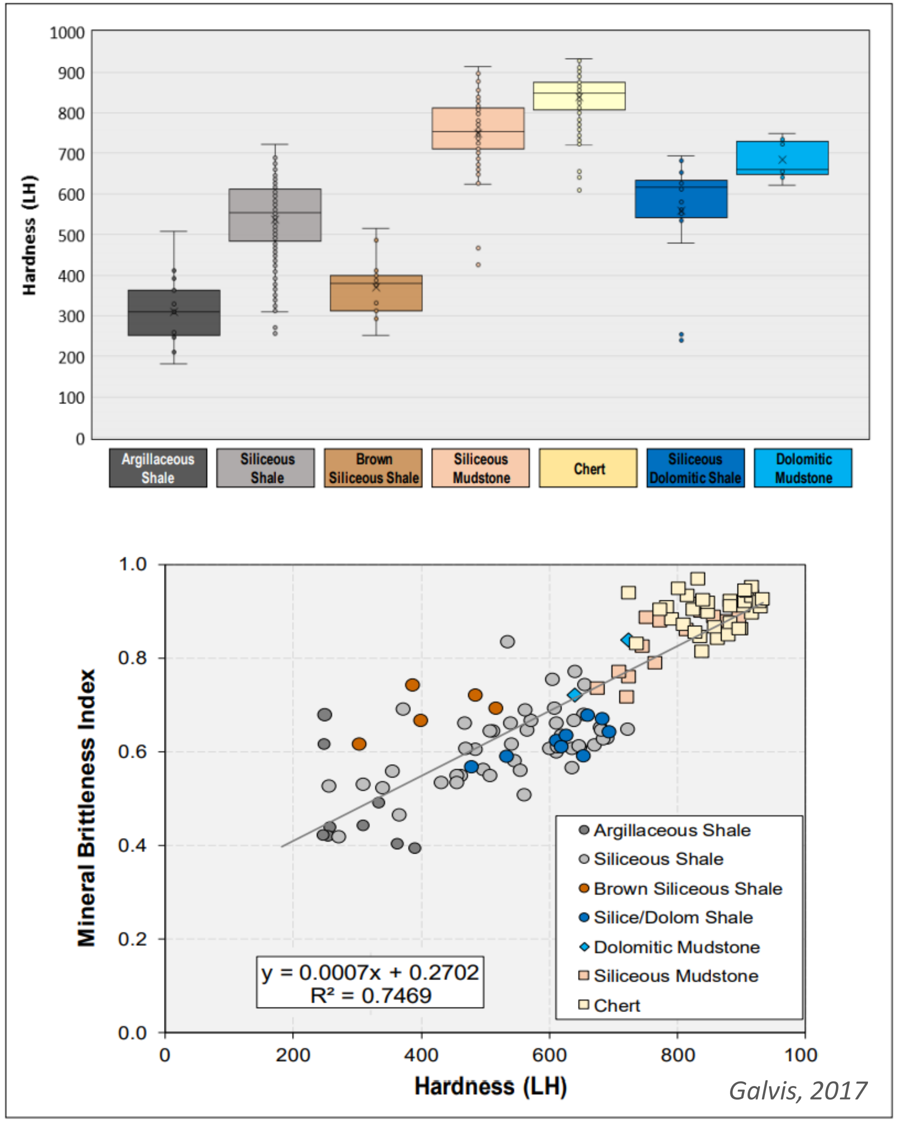
Hardness

Modified from Becerra (2017)



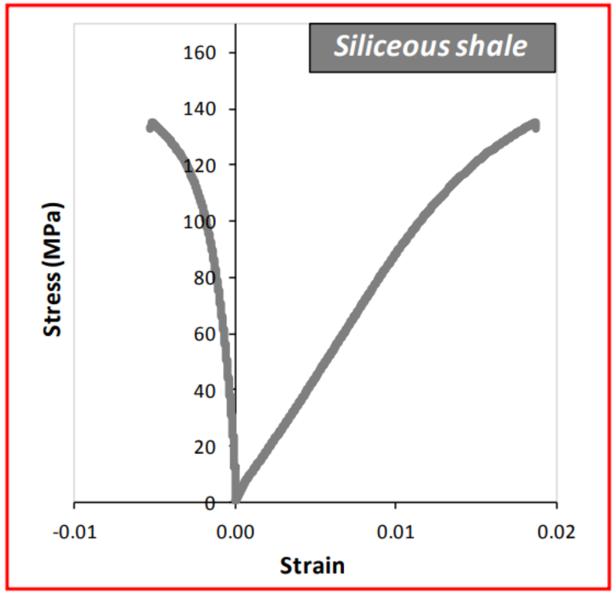
$$Hardness\ (LH) = \frac{Rebound\ velocity\ (Vr)}{Impact\ velocity\ (Vi)} * 1000$$

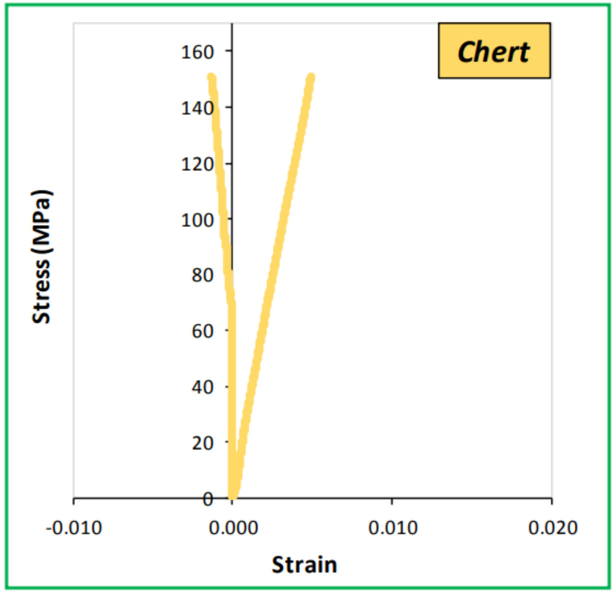
Becerra, 2017



Galvis, 2017

Brittle - Ductile

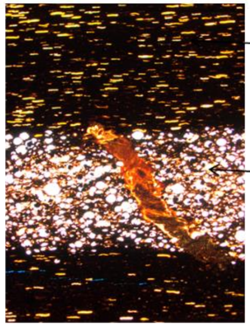


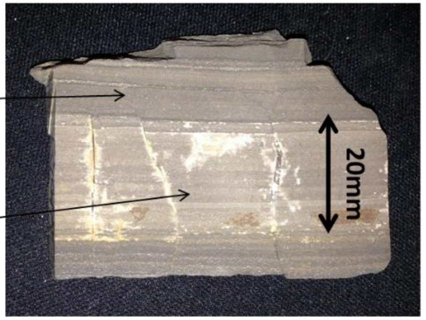


Weathering Response	Lithofacies	UCS (Mpa)	Young's Modulus (GPa)	Poisson's Ratio	Hardness (LH)	Mineralogical Brittleness Index	Stress-Strain Brittleness
Soft	Siliceous Shales	135	9	0.2	540	0.69	0.82
Hard	Chert	153	27	0.14	815	0.92	0.98

Becerra, 2017

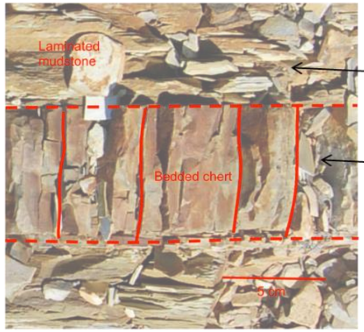
Natural Fractures, Woodford Shale: The effect of lithology





Mudstone

Chert

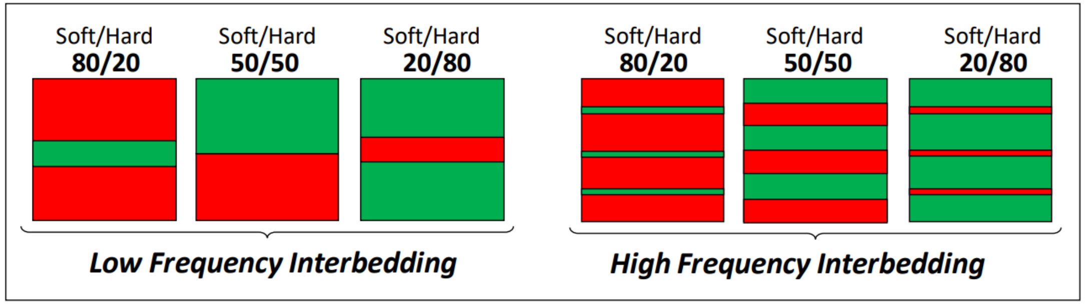


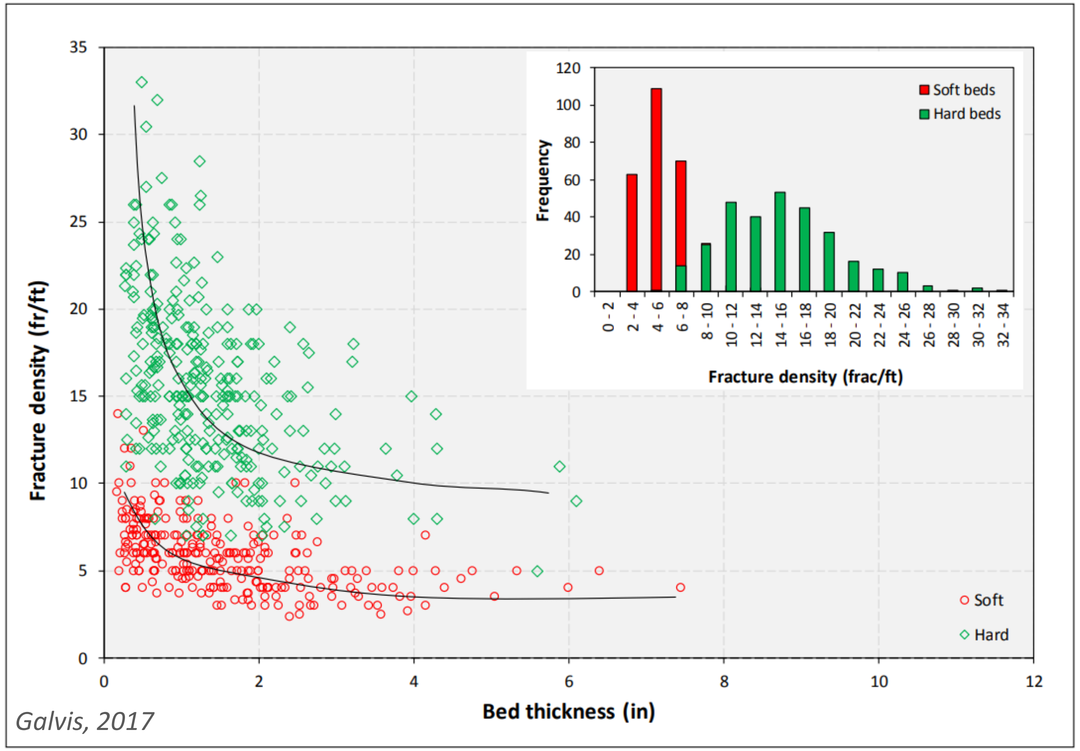
Mudstone

Chert

"Brittle-Ductile Couplets"
(Slatt and Abousleiman, 2011)

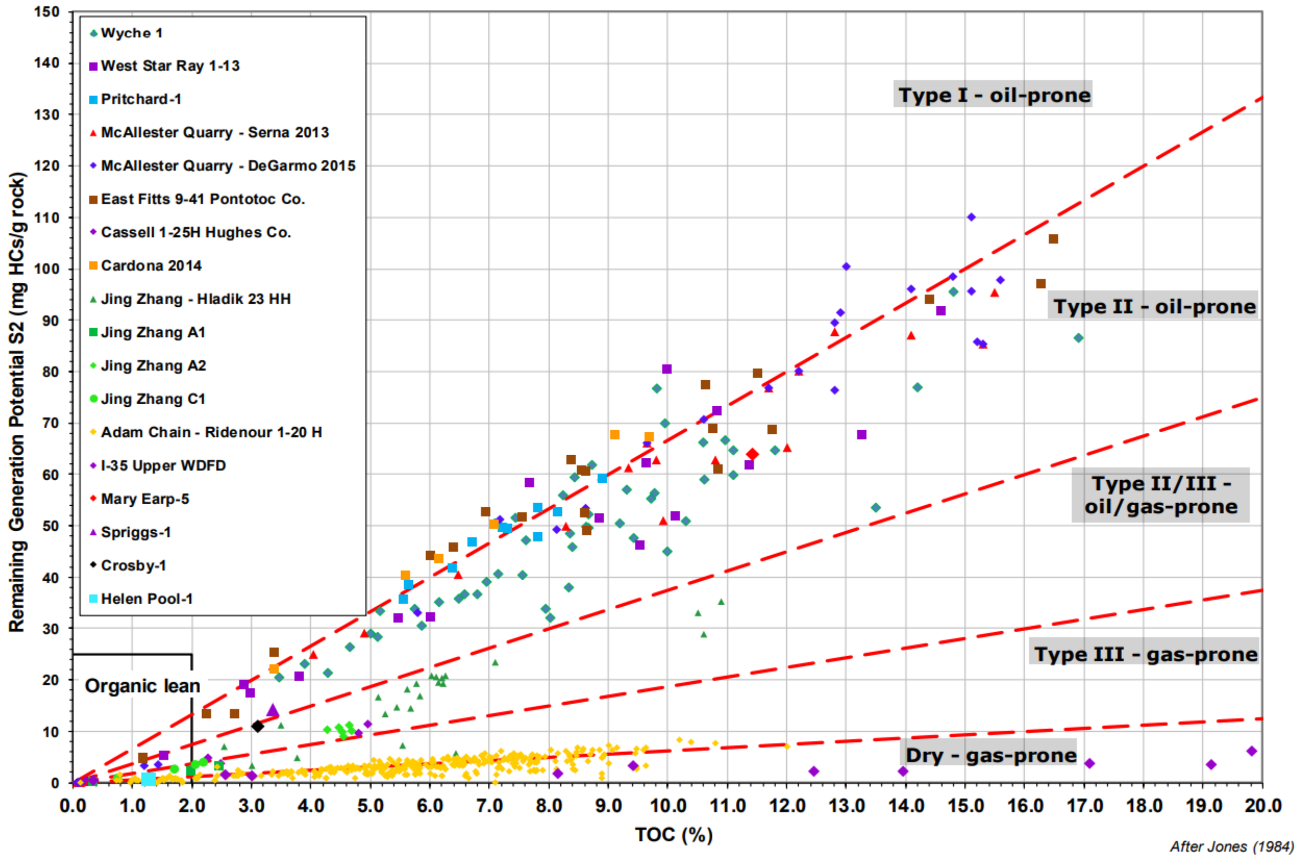
Fractures vs. Bed Thickness





Cross-plot of fracture density and bed thickness. Histogram displaying fracture density measured along scan-lines. Note the greater amount of fractures within hard beds n= 576.

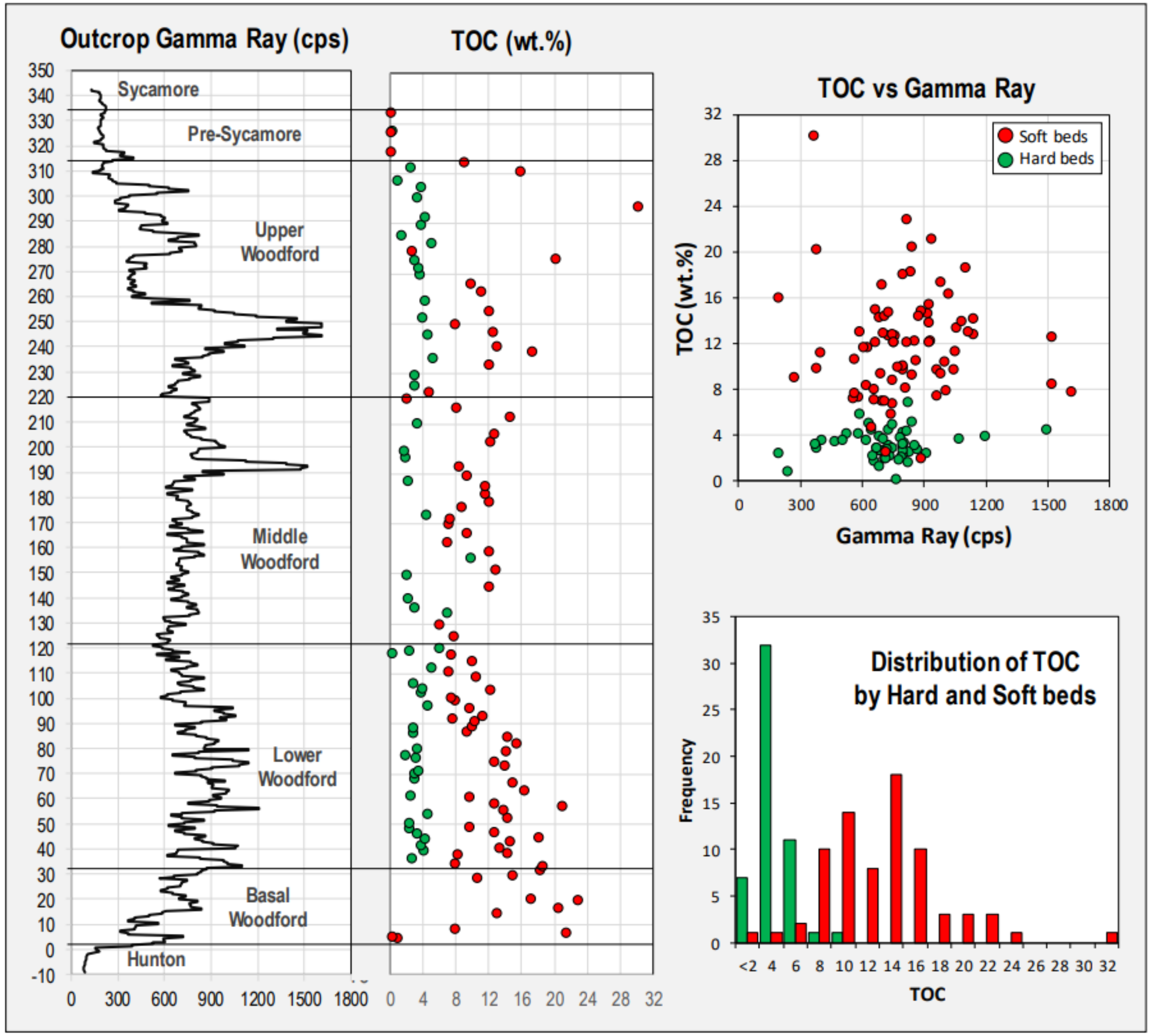
Geochem: Organic Richness



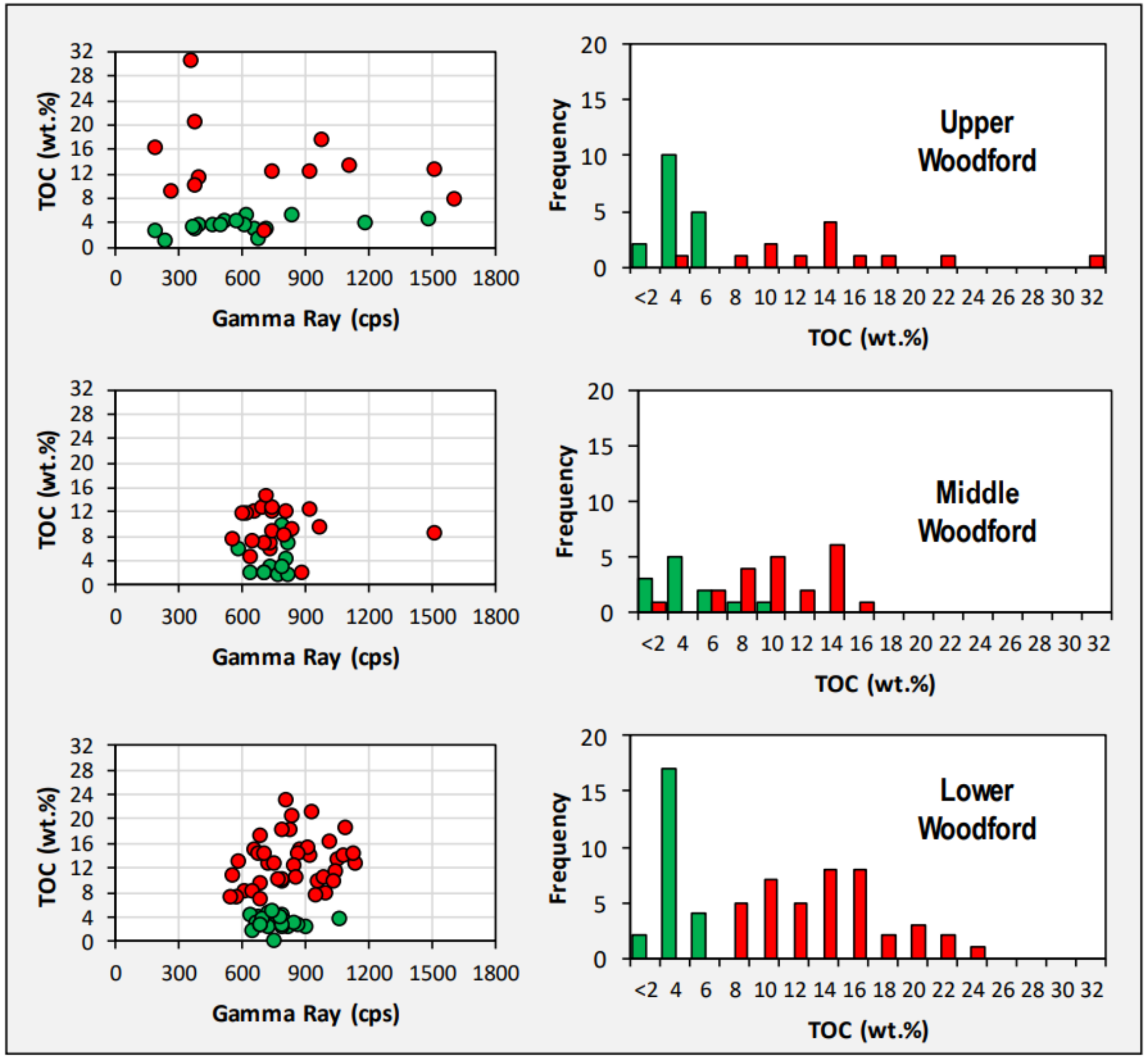
Torres, 2020

Figure B.9. Rock-Eval remaining hydrocarbon potential (S_2) vs. TOC plot for determination of kerogen type and maturity for all the 553 Woodford Shale core, cuttings, and outcrop samples. Note that most of the samples plot in the type II Kerogen area, but some are in the type I kerogen yield. The Ridenour 1-20H well shows a high maturity level and apparent type III kerogen because of the depletion of S2 by thermal cracking.

TOC vs Hard/Soft Facies

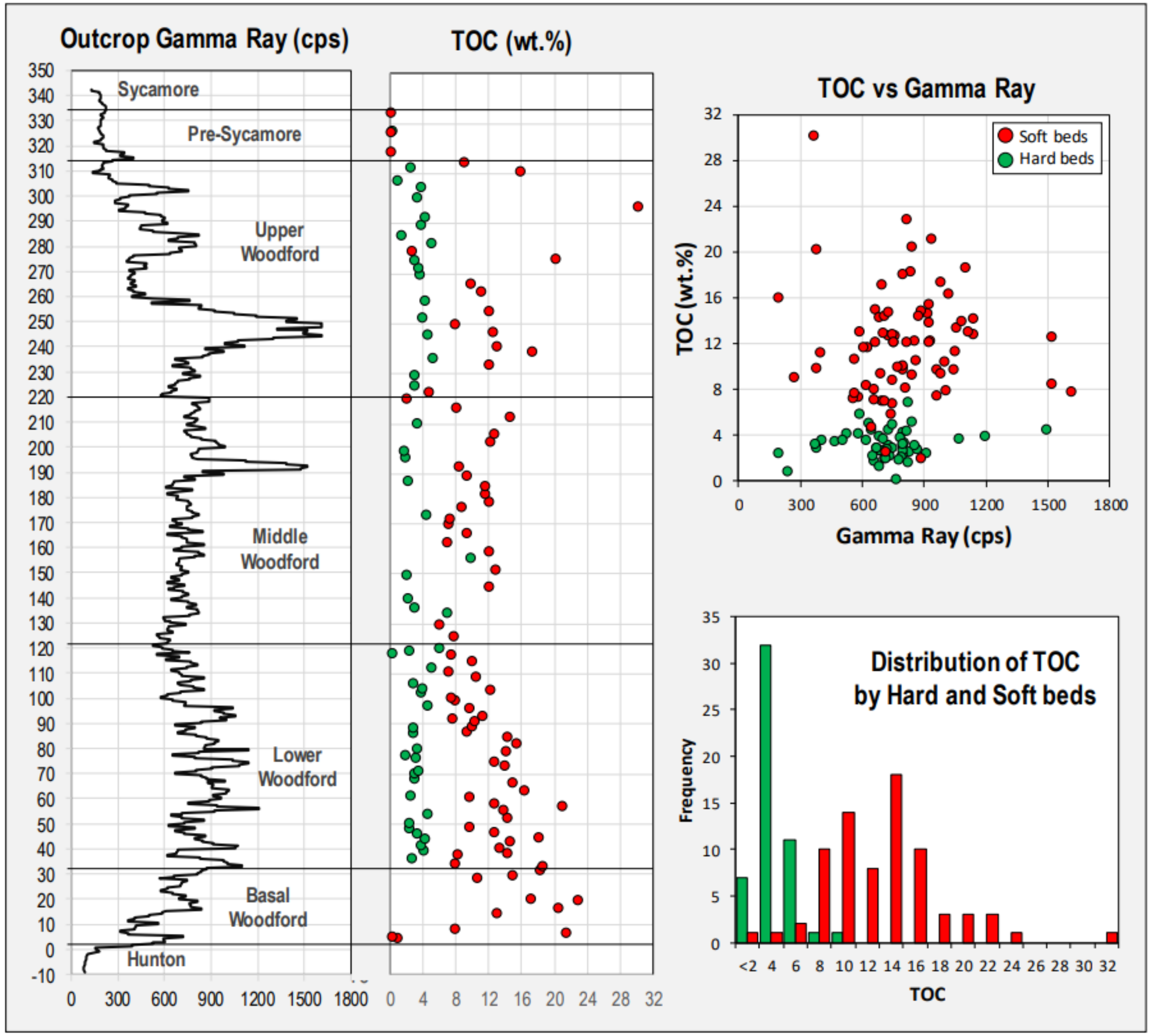


Galvis, 2017

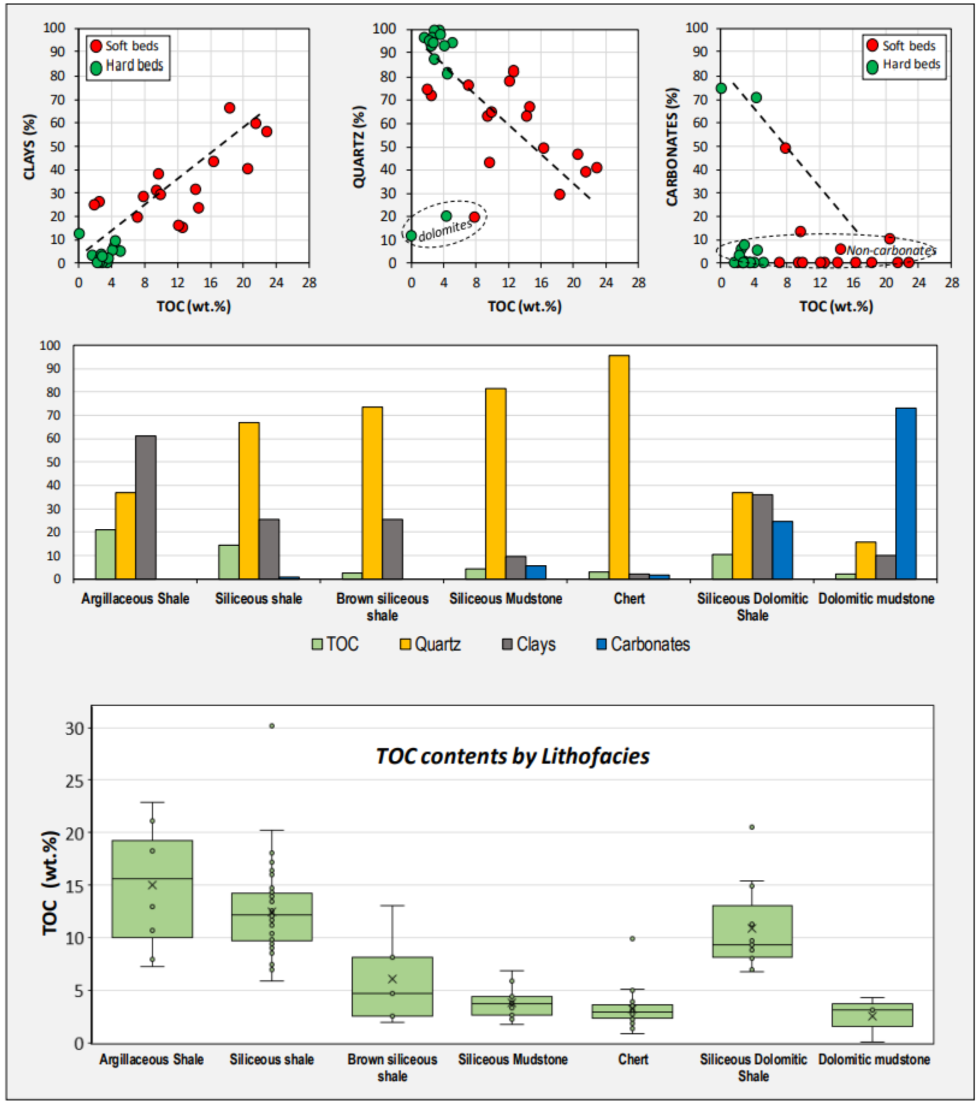


Galvis, 2017

TOC vs. Facies

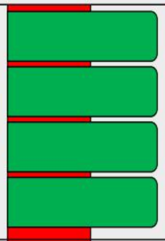
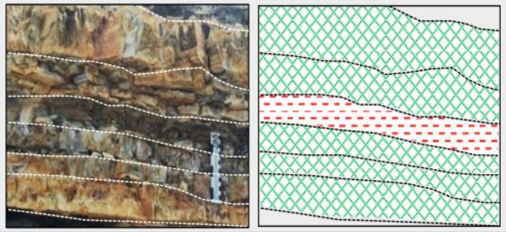
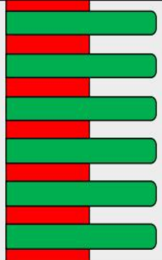
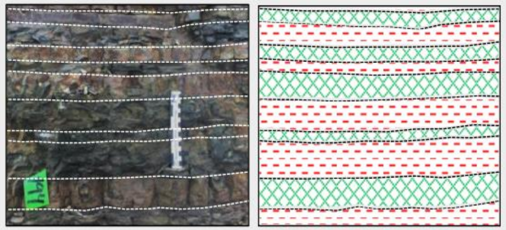
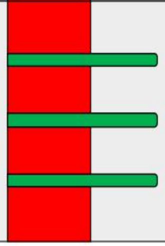
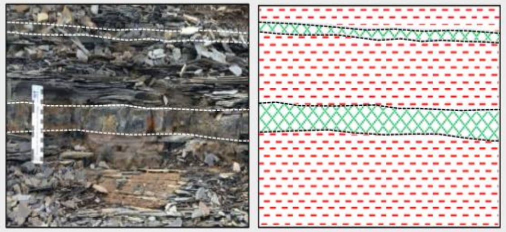


Galvis, 2017

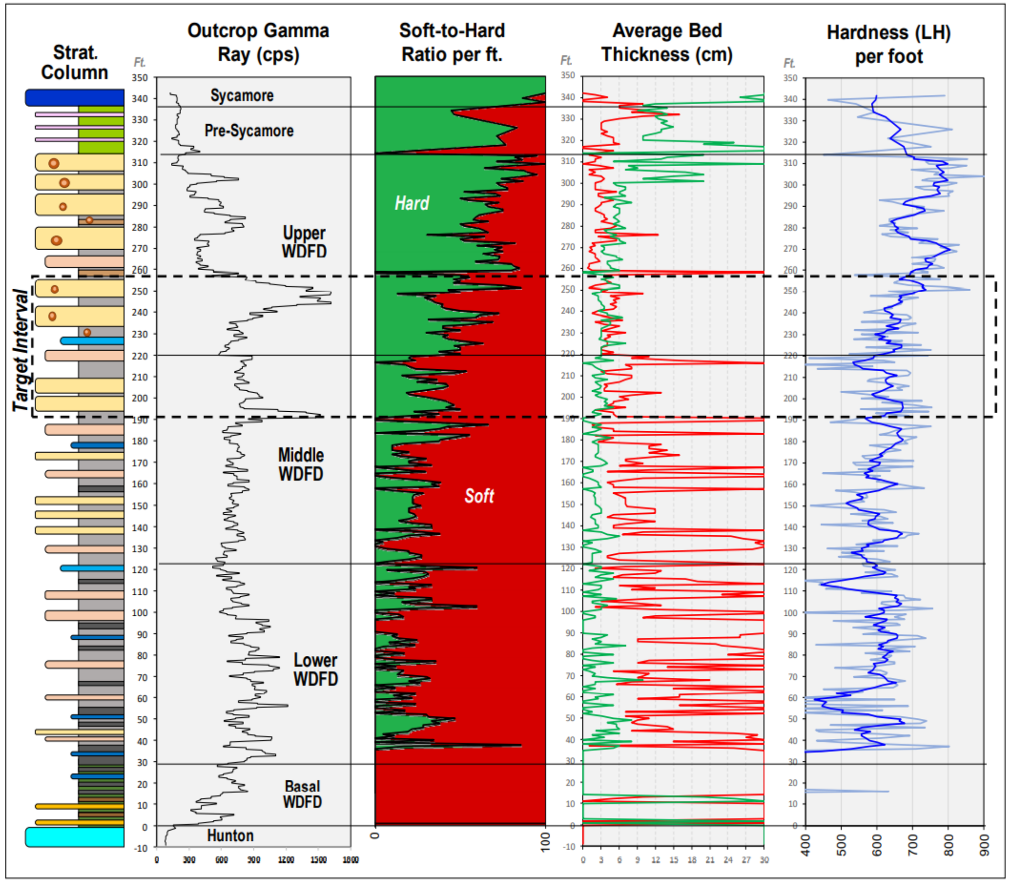


Galvis, 2017

RQ and CQ Model

Stacking Pattern		Characteristics	RQ and CQ	Woodford Examples
Model 3		**Hard >>> Soft** * Thick chert beds (8-12 cm) * Very thin shale beds (<3cm) * Moderate organic contents (<5%) * Very Hard (high UCS and Brittleness) * Moderate natural fracture intensity	**Better QC – Poor RQ** * Fracturability, high fracture conductivity * Efficient proppant placement * Low potential as a hydrocarbon source rock (Low expulsion efficiencies) * Poor matrix porosity	
Model 2		**Soft ≈ Hard** * Homogeneous bed thickness (~4 cm) * High frequency interlayering (thinly) * Organic-rich shales and brittle cherts * Moderate Hardness * Very high natural fracture intensity	**Balance between RC and CQ** * Storage capacity in fractures of cherts as in the shale matrix primary porosity * Development of more complex hydraulic fractures * Excellent matrix-fracture connectivity * Efficient proppant placement	
Model 1		**Soft >>> Hard** * Thick shale beds (>10cm) * Very thin scattered chert beds (<3cm) * Excellent organic contents (8-20%) * Low Hardness (high ductility) * Very low density of natural fractures	**Better RQ – Poor CQ** * Super high potential as a hydrocarbon source interval (with matrix storage) * High ductility, Low fracability * Poor reservoir connectivity * Proppant embedment	

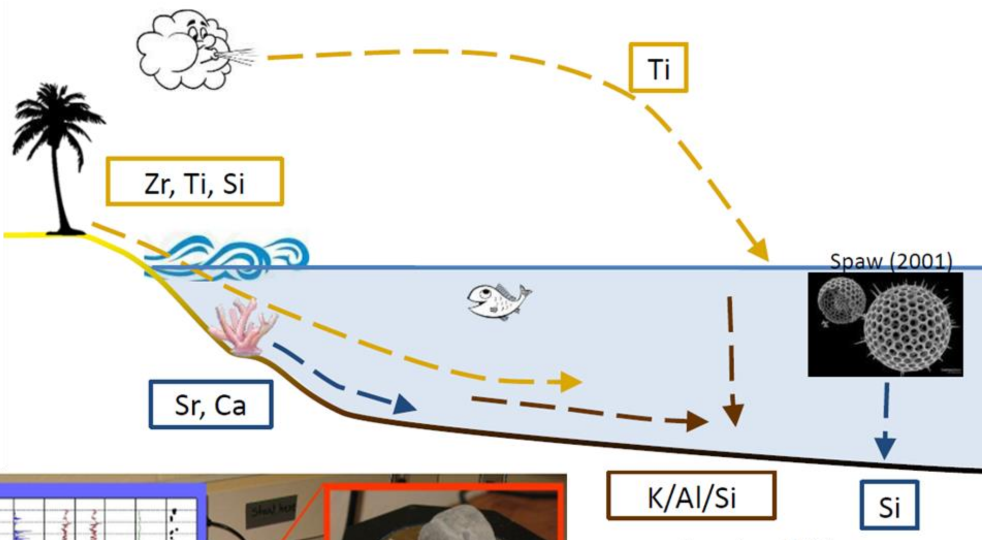
Galvis, 2017



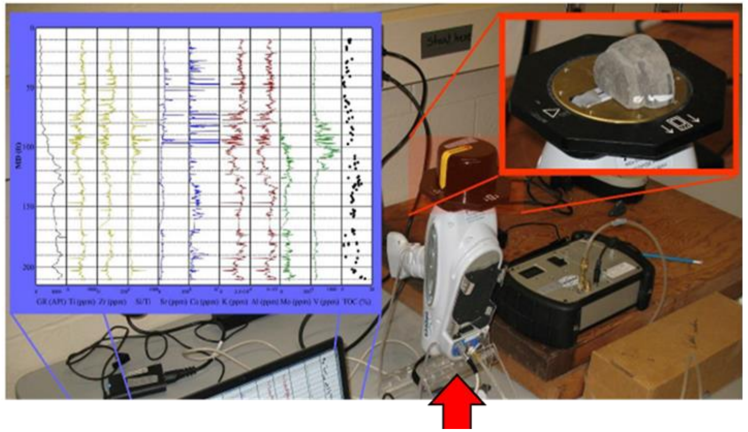
Galvis, 2017

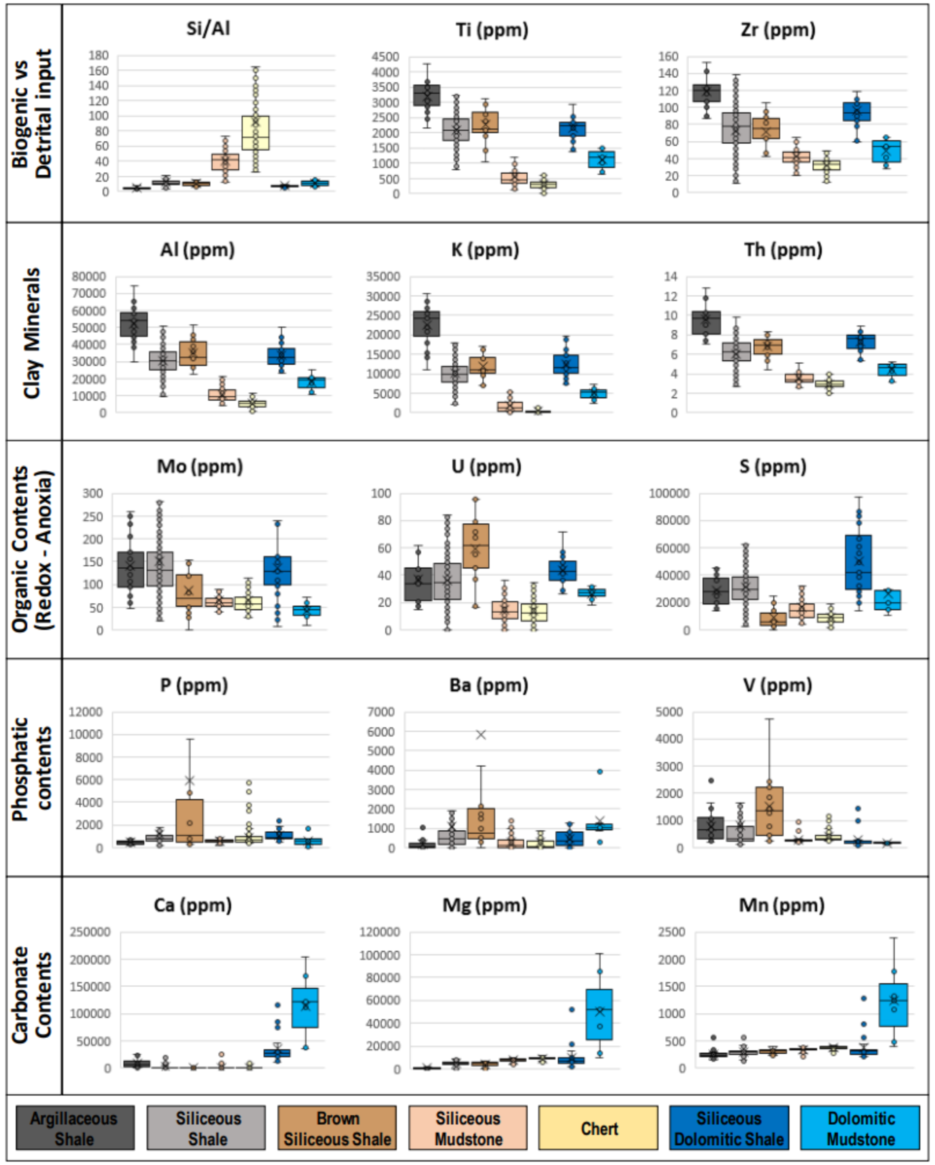
Chemostratigraphic Proxies

	Majors	Trace
Count Time:	*90 sec*	*60 sec*
Accelerating Voltage:	*15 kV*	*60 sec*
Filter:	*No*	*Yes (Ti-Al filter)*
Vacuum:	*Yes (<5 torr)*	*No*



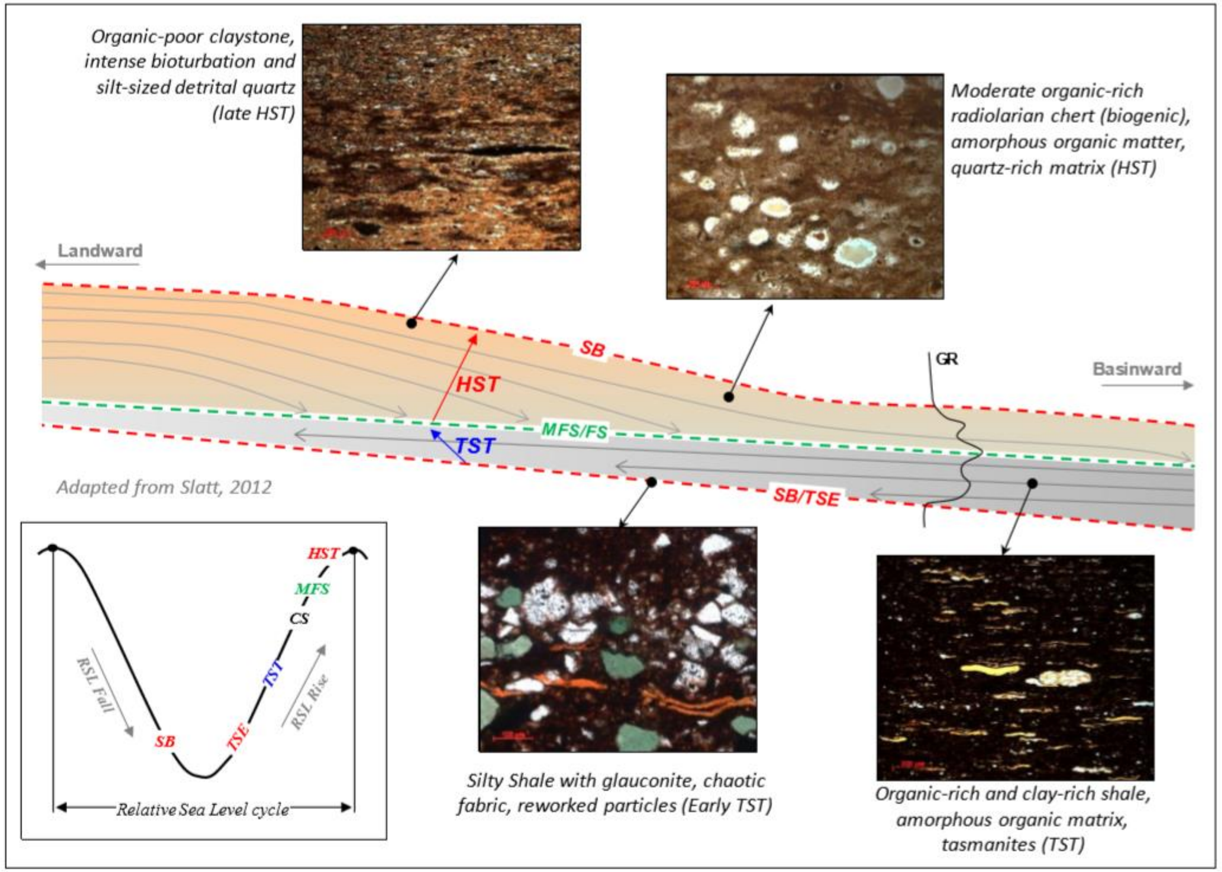
Treanton, 2014



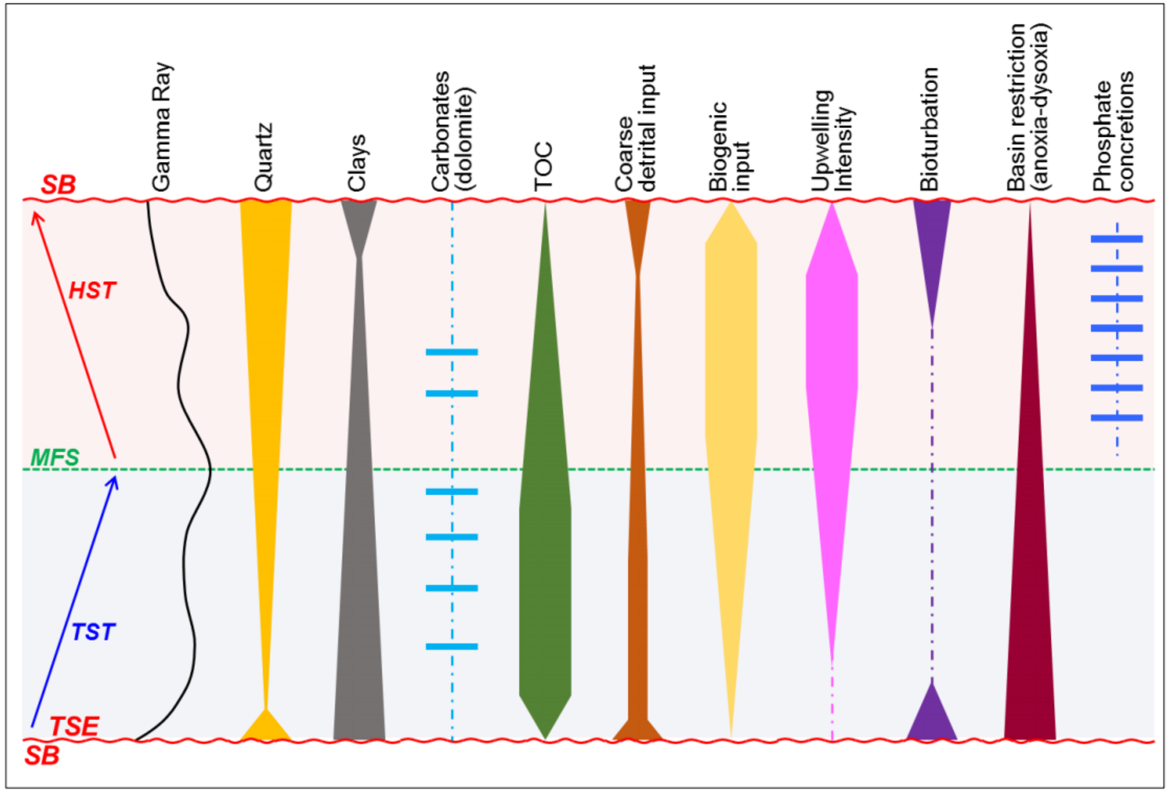


Galvis, 2017

Back to Sequence Strat Model



Galvis, 2017



Galvis, 2017

Summary

✓ The Woodford Shale is a Late-Devonian/Early Mississippian deposit mainly composed of 4 major facies:

- Argillaceous Shale and Siliceous Shale
- Siliceous Mudstone and Chert
- Other minor dominant facies: Dolomitic Mudstones/Shales and Green Claystones

✓ These facies can be grouped in **"Soft"** (less brittle) and **"Hard"** (more brittle) rock types. Most of their geochemical (RockEval - TOC) and geomechanics properties (Hardness, Brittleness, Fractures) are driven by the alternation and proportion these two groups along the stratigraphic package and what mineralogy dominates.

✓ There is evidence of early formation of fractures before compaction that are bounded by bedding/facies and fracture density/frequency are directly related to bed thickness.

✓ The Woodford Shale depositional model consist of an early TST and a late HST. Chemostratigraphy is an excellent tool/methodology to interpret the changes in depositional trends by looking a XRF proxies particularly the interplay between biogenic and detrital deposition.

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Acknowledgments

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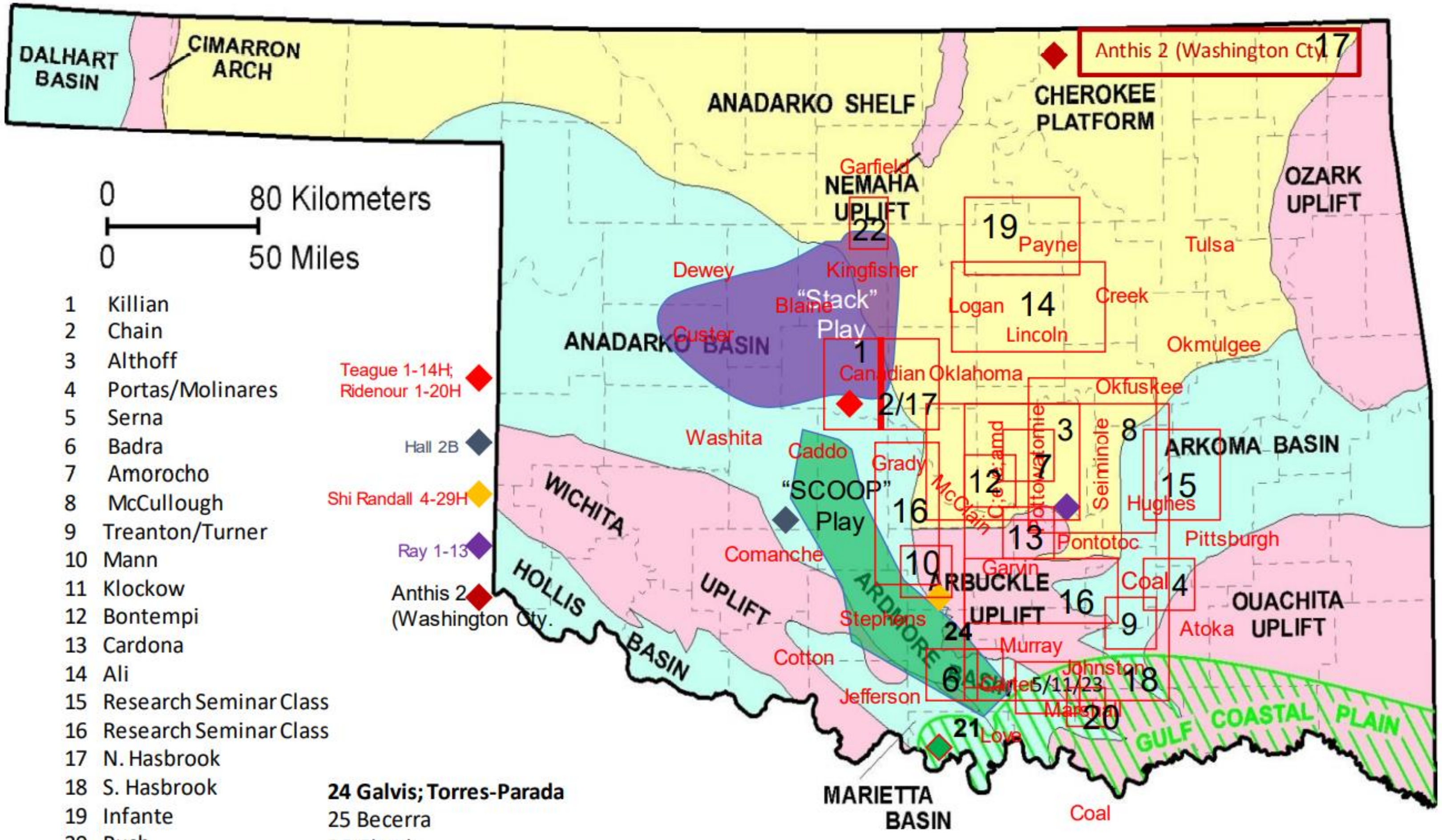

1 Killian
2 Chain
3 Althoff
4 Portas/Molinares
5 Serna
6 Badra
7 Amorocho
8 McCullough
9 Treanton/Turner
10 Mann
11 Klockow
12 Bontempi
13 Cardona
14 Ali
15 Research Seminar Class
16 Research Seminar Class
17 N. Hasbrook
18 S. Hasbrook
19 Infante
20 Rush
21 Brito
22 Zhang
23 Ifunanya
24 Galvis; Torres-Parada
25 Becerra
26 Ghosh
27 Maynard
28 Totten
29 Sierra; Molinares