The Effect of Karsting on Natural Fracture, Hardness, and Brittleness of the Hunton Limestone and Paleo-Deposition of the Woodford Shale: A Study Using 3-D Seismic, Outcrop, Well Log, and Core Data*

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Search and Discovery Article #51417 (2017)**
Posted August 21, 2017

*Adapted from oral presentation given at AAPG 2017 Southwest Section Annual Convention, Midland, Texas, April 29-May 2, 2017

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Abstract

Much of the oil and gas production in Oklahoma, U.S.A., is from carbonates and shales, such as the Viola Limestone, Sylvan Shale, Hunton Limestone, and Woodford Shales. Karsting is a common feature of carbonate environments, which causes topographic irregularities on an unconformity surface. In parts of the Cherokee platform (Central Oklahoma), the Hunton Limestone lies beneath the Woodford Shale and it might have controlled Woodford deposition. The study is undertaken to 1) understand the impact of karsting on the natural fractures in the Hunton Limestone, 2) study the effect of the unconformity karst surface on the overlying Woodford Shale, 3) evaluate the hardness of the Hunton Limestone and the Woodford Shale for artificial fracture stimulation, 4) determine the geomechanical properties, such as young's modulus, poisson's ratios, and brittleness index from well logs, and 5) describe the lithology and nature of the boundary contact between the Hunton Carbonate and the Woodford Shale. To accomplish this study, we used thin sections, core, outcrop, well logs, and a 3-D seismic survey data.

A 3-D seismic survey and well logs were used to map the structure and thickness of the Viola Limestone, Sylvan Shale, Hunton Limestone, and the overlying Woodford Shale. The Hunton unconformity in Central Oklahoma are affected by karst features, such as collapse and sinkholes on the Hunton unconformity surface. These karst features are prominent factors controlling the paleotopography and deposition of the Woodford Shale, as was observed from 3D structural maps. Sinkhole features in 3-D structural maps range in diameter from 1150 to 2300 ft. and extend vertically to almost 300 ft. These sinkholes have a potential effect on the deposition of the overlaying Woodford Shale. Similarly, there might have been a potential effect of the Viola Limestone karstification on the overlying Sylvan Shale. The thickness variations of the Woodford Shale are controlled by paleotopography of the underlying Hunton Group where thicker Woodford is observed in the karst lows (sinkholes). Additionally, the structural maps show an inverse correlation between the thickness of limestones (Viola and Hunton) and shales (Sylvan and Woodford).

We quantified the fracture intensity and apertures manually using comparator and hand lens at core site as well as using Image J software^{TM}. Fractures in the Hunton core are affected by the karstification on the Hunton unconformity. Core data reveals that fractures exist only in the

karstified section of the uppermost 15 ft. of the Hunton due to karstification. The fracture aperture (sealed) ranges from 0.003 to 0.01 in. and the fracture intensity ranges from 8 to 30 fractures/ ft. every 6 inches (on average) along the core length. The higher hardness measurements correspond to areas with higher fracture abundance due to more brittle rocks in the karsted zone. Additionally, a core that consists of the Hunton Group, boundary contact, and Woodford Shale was studied to quantify the fracture aperture and intensity, measure the hardness using a Rebound Hammer™, and describe the lithology and nature of the boundary contact. The studied core exhibits an erosional unconformity surface between the Hunton Limestone and the overlying Woodford Shale with possible Misener Sandstone.

In addition, bulk density as well as shear and compressional wave travel times were used to determine young's modulus, poisson's ratios, and brittleness index for the Viola Carbonate, Sylvan Shale, Hunton Carbonate, and Woodford Shale to aid in picking brittle areas for fracturing/ refracturing plans. The Hunton interval has the highest brittleness index (average of 0.8) among the Viola, Sylvan, and Woodford formations. However, Sylvan Shale has the lowest brittleness index (average 0.35). The Viola Limestone has brittleness index (average 0.6). Additionally, the brittleness index for the Woodford Shale stratigraphic interval in the studied area vary from 0.4 to 0.8. This study predicts the locations of thick Woodford Shale sections suggesting possible spots for landing horizontal wells in the Woodford Shale. Also, the high brittleness index from well logs can be used as a proxy to target a zone for hydraulic fracturing through the Viola Carbonate, Sylvan Shale, Hunton Group Carbonate, and the Woodford Shale.

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By

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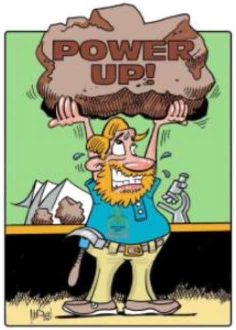
The University of Oklahoma

Southwest Section - AAPG 2017 Convention

Midland, Texas

May 2, 2017



Outline

- Objectives
- Geological setting
- Area of Study & Data Available
    - Core analysis
    - Well logs
    - Outcrop
    - 3D Seismic Volume
- Methodology
- Conclusions
- References
- Acknowledgments

Objectives

The main objectives of this study are to:

1) understand the impact of **karsting** on the natural **fractures** in the Hunton Limestone

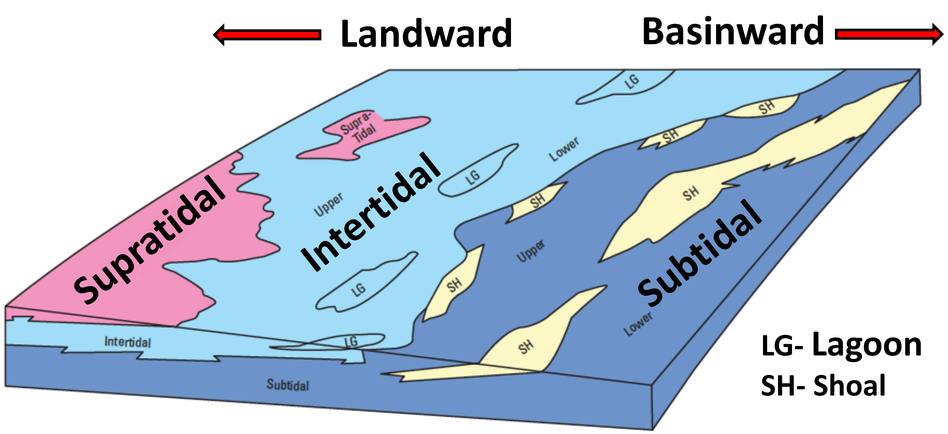
2) study the effect of the **unconformity** karst surface on the overlying **Woodford** Shale in terms of the stratigraphic thickness, and

3) evaluate the **hardness** of the Hunton Limestone and the Woodford Shale for artificial fracture stimulation

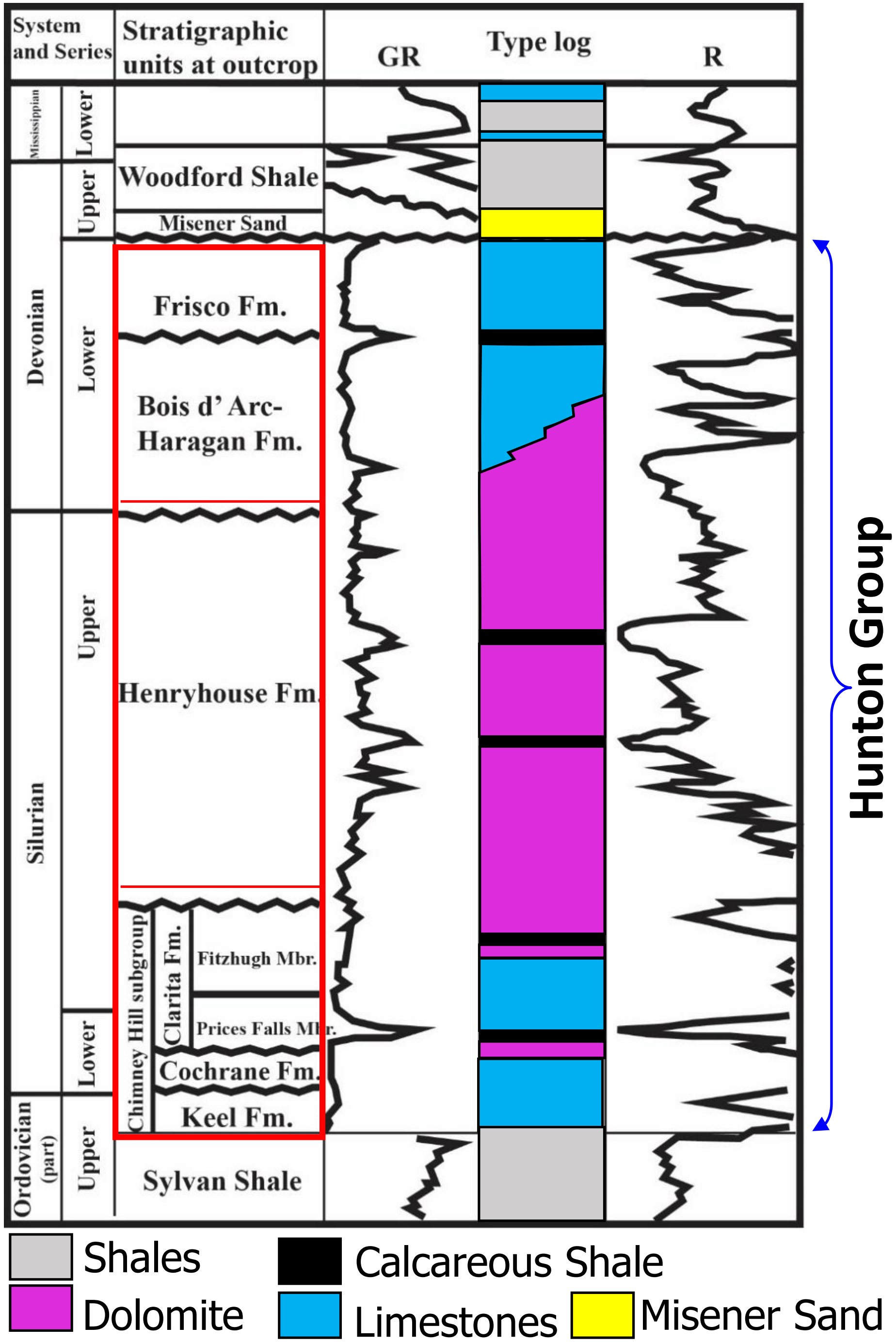
4) determine the **geomechanical properties**, such as young's modulus, poisson's ratios, and brittleness index from well logs, and

5) describe the **lithology** and nature of the **boundary contact** between the Hunton Carbonate and the Woodford Shale.

Geological Setting



- Shallow-water carbonate ramp sequence <1/5°
- Hunton strata deposited at several places
- Between the Ordovician Sylvan Shale and late Devonian Woodford Shale.
- Three major subdivisions
- Mainly limestone and dolomite.
- The Hunton ranges from 100 to **400** ft thick

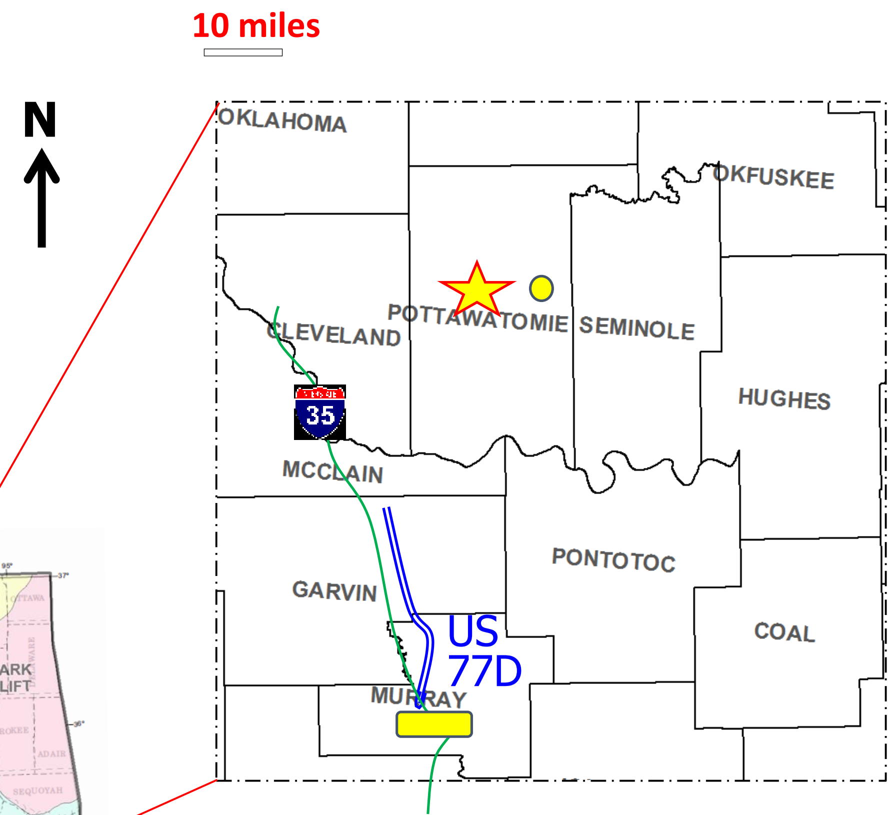


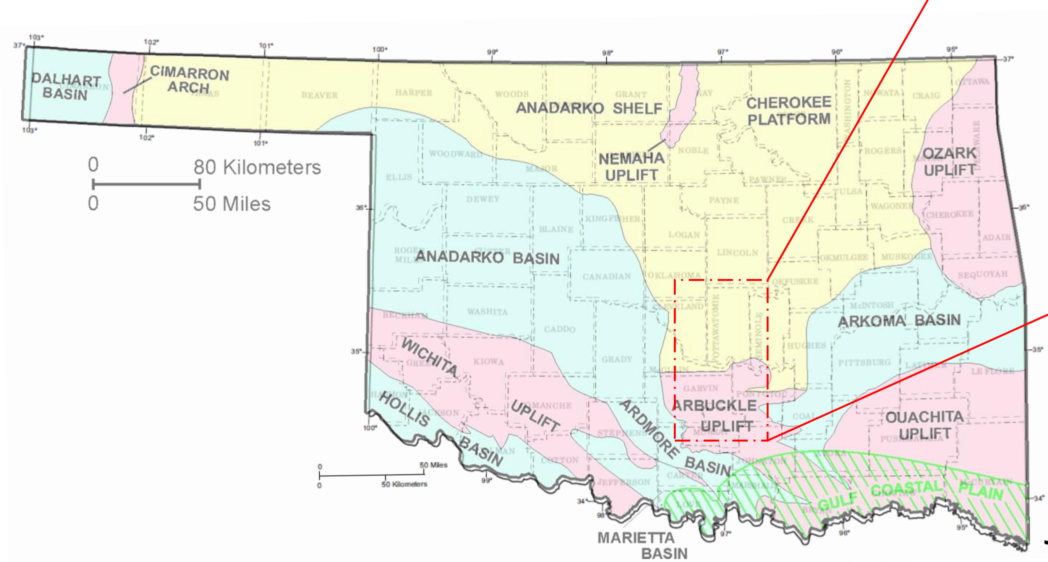
Benmadi Milad (2017) (Modified from Fitz and Medlock, 1994)

Area of Study & Data Available

Data Available

- Core analysis
- Well logs
- Outcrop
- 3D Seismic Volume





Johnson et al. 2008

Methodology

Fracture analysis

- ✓ Comparator and hand lens
- ✓ Image J software

Lithology description

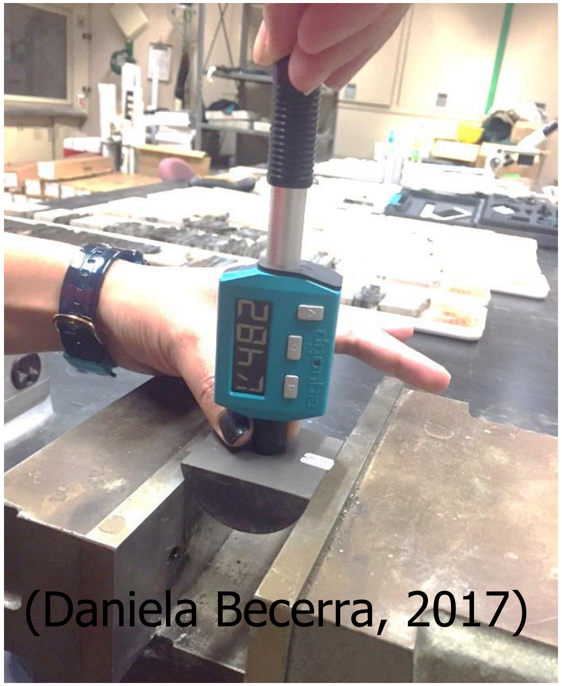
- ✓ Thin sections
- ✓ Core GR
- ✓ Core porosity and permeability

Hardness

- ✓ Rebound Hammer
- ✓ 5-10 measurements every 6 inches. Then take average value

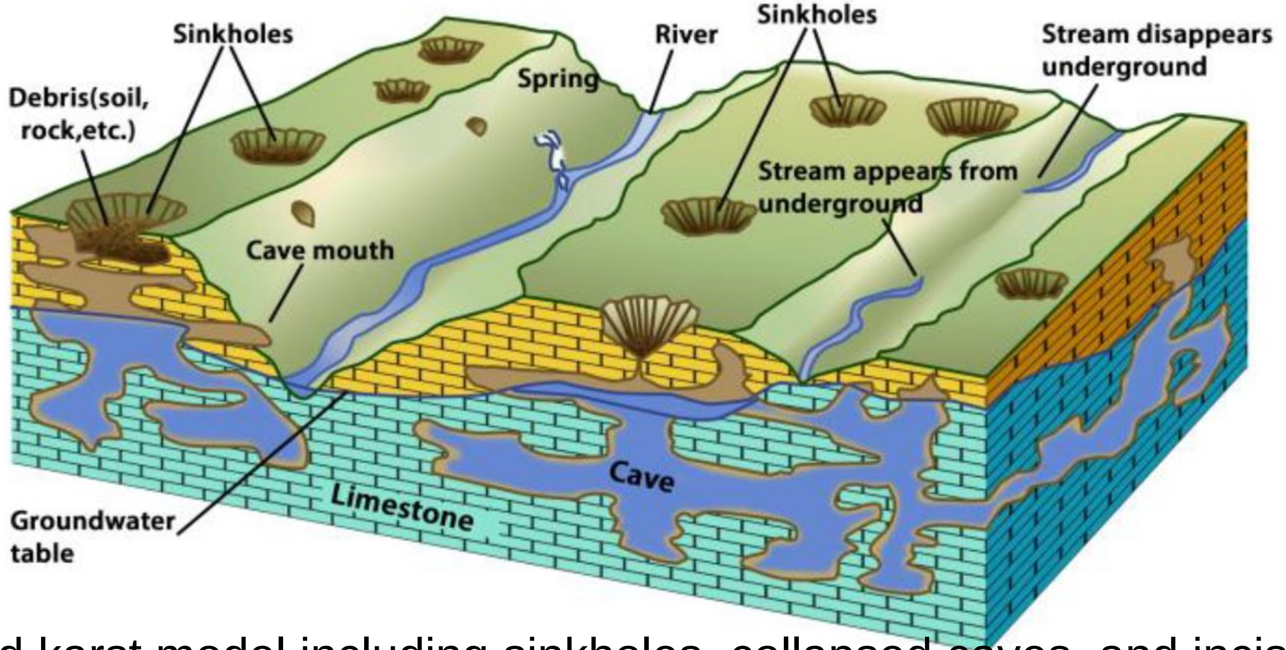
Stratigraphic Correlations

- ✓ Well logs
- ✓ 3D seismic Survey


(Daniela Becerra, 2017)

Karstification

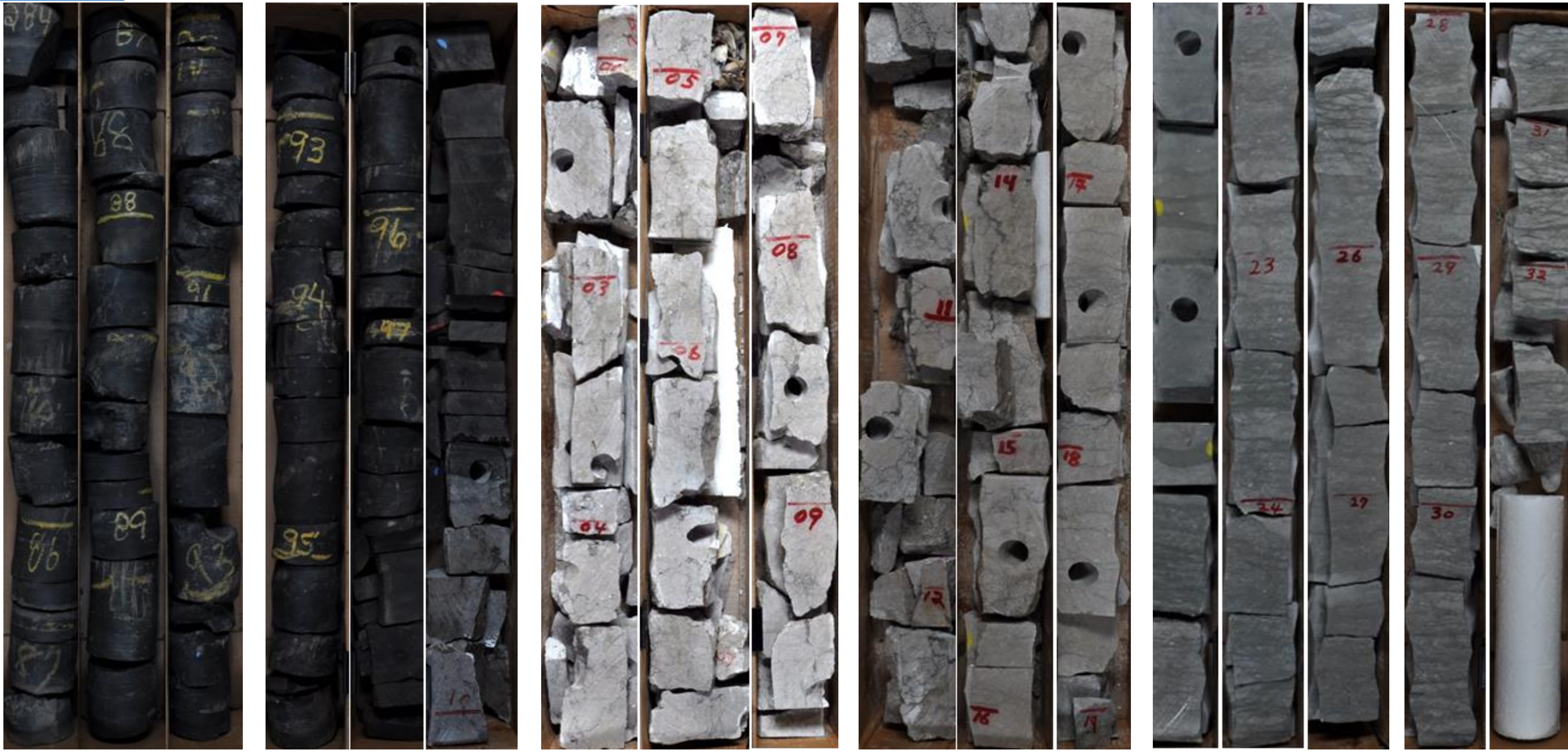
- Karsting is a common feature of tropical carbonate during green house period (Moore, 2013).
- During lowstands, erosion is dominantly chemical (Moore, 2013).
- Long-term exposure leads to karsting (Moore, 2013).
- The chemical diagenesis including dissolution, remobilization, and precipitation of calcium carbonate produce karst.
- Dissolution Processs: CaCO3 + H2O + CO2 ↔Ca+2 + 2HCO3^{-}



Generalized karst model including sinkholes, collapsed caves, and incised valleys. (Grotzinger and Jordan, 2010).

Hunton and Woodford Core

5284



5332

Milad and Slatt (2017)

Karst features

5310

1 ft

5319

Mosaic breccia is composed of largely connected clasts, but not wholly disjointed and displaced.

Stylolite is a result of pressure dissolution

5302

1 ft

5310

Crackle breccia is extensively fractured and fragmented and has not moved

Vugs

Collapse breccia is a result of structural collapse of a cave roof into a previously open cavern

Woodford Core

5284

5293

Features

Micro cross bedding

Quartz= white color

Intraclast= black color

Pyrite?Phosphae (?)

Quartz= white color

Fragment of crinoids

Burrows

Wdf-Hunton Contact

Descriptions

Siliceous Shale, indurated, microlenses of siltstone, wavey lamination at the base, some pyrite, black dark color, non-calcareous, pyritize burrows, sharp contact at the base

Siltstone, wavy laminations, soft deformation gradational contact at the base

Fine to v fine sandstone, lithics, calcareous,fizzis, phosphates intraclasts, massive, traces of pyrite(?), Glauconite(?), erosional unconformity surface at the base. **Misener sandstones** (?)

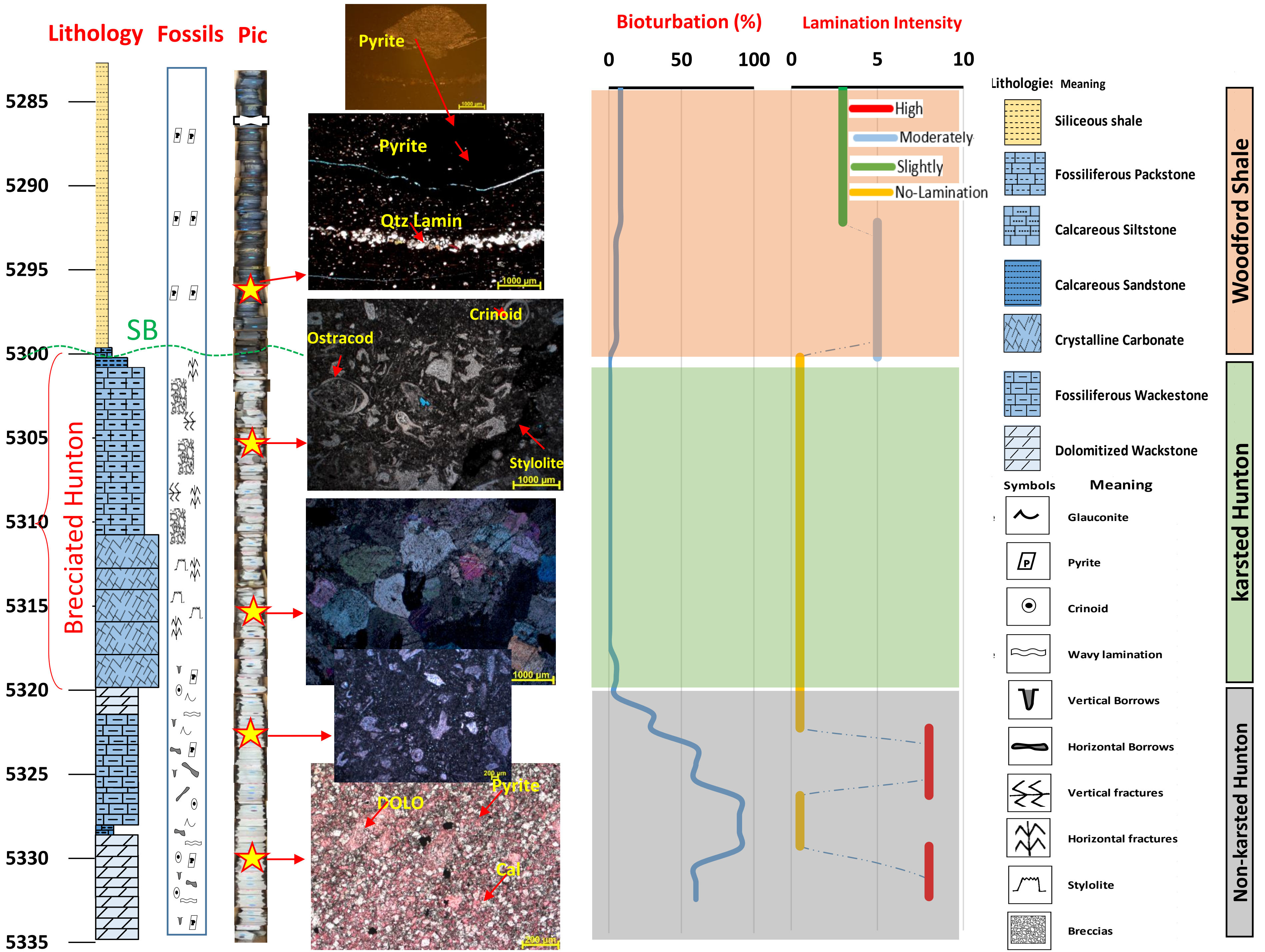
Crystalline limestone, Chaotic arrangement of particle of crinoids, intraclasts, phosphates, slightly burrowed

5293

1 ft

5301

Milad and Slatt (2017)



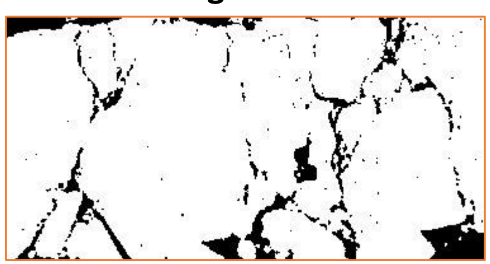
Lithology
Fossils
Pic
5285
5290
5295
5300
5305
5310
5315
5320
5325
5330
5335
SB
Brecciated Hunton
Pyrite
Pyrite
Qtz Lamin
1000 µm
Crinoid
Ostracod
Stylolite
1000 µm
1000 µm
200 µm
DOLO
Pyrite
Cal
200 µm
Bioturbation (%)
0
50
100
Lamination Intensity
0
5
10
High
Moderately
Slightly
No-Lamination
Lithologies
Meaning
Siliceous shale
Fossiliferous Packstone
Calcareous Siltstone
Calcareous Sandstone
Crystalline Carbonate
Fossiliferous Wackestone
Dolomitized Wackstone
Symbols
Meaning
Glauconite
Pyrite
Crinoid
Wavy lamination
Vertical Borrows
Horizontal Borrows
Vertical fractures
Horizontal fractures
Stylolite
Breccias
Woodford Shale
karsted Hunton
Non-karsted Hunton

Fracture Methodology using Image J Software

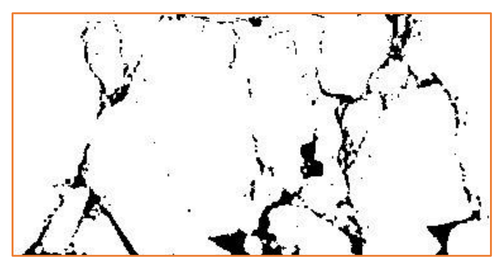
1.83 in

3.64 in

Thresholding

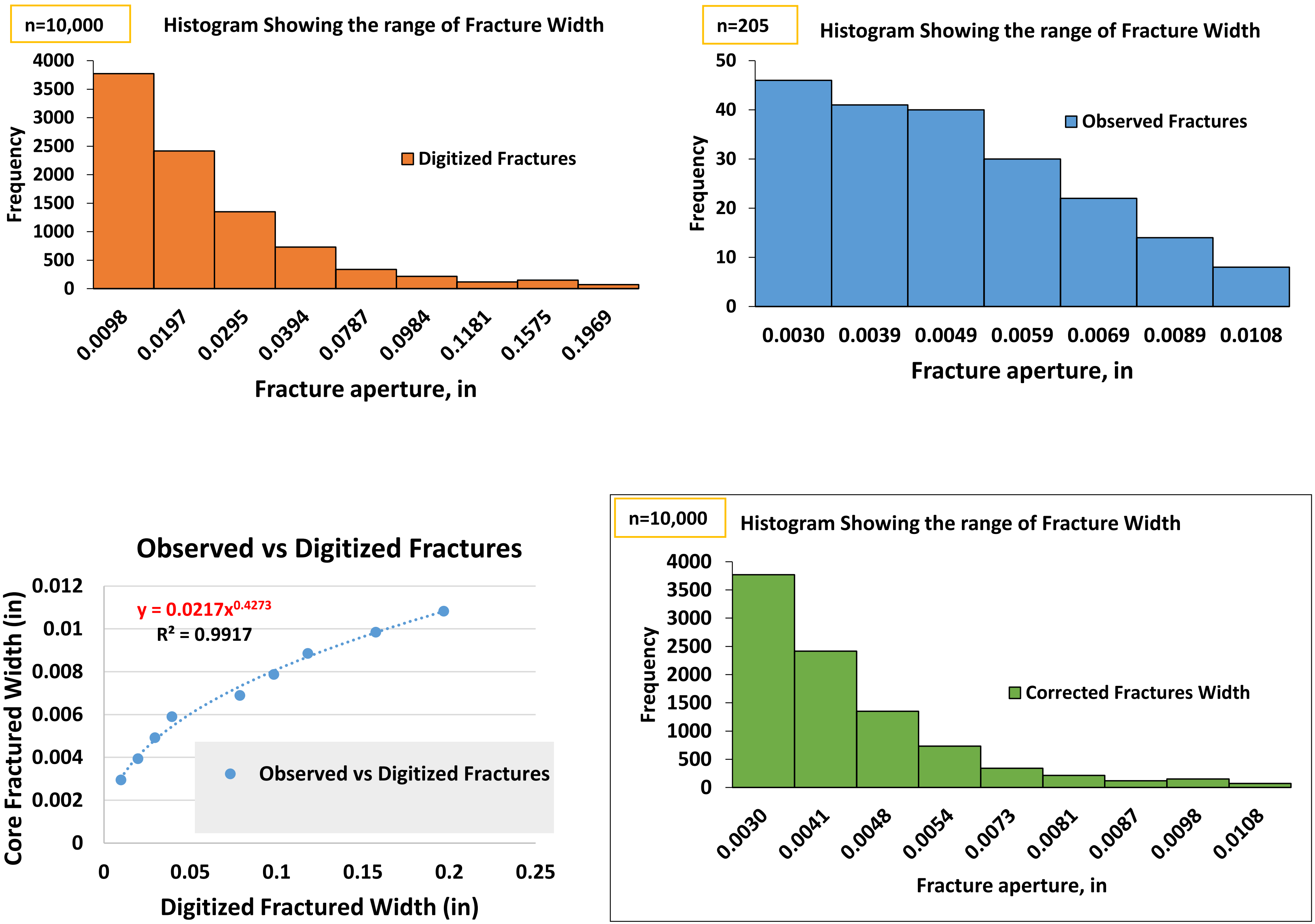


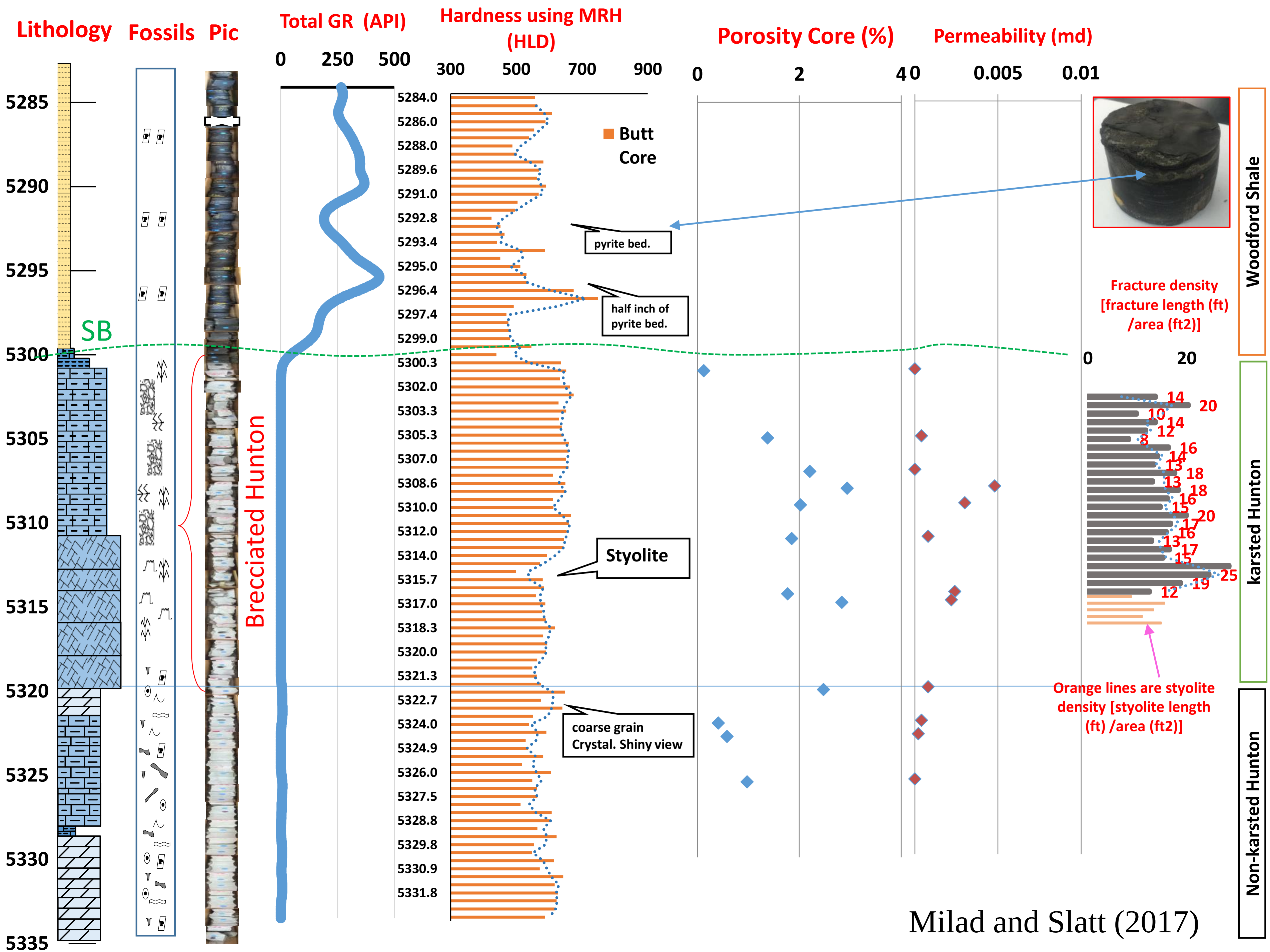
Thresholding+ Cleaning



Milad and Slatt (2017)

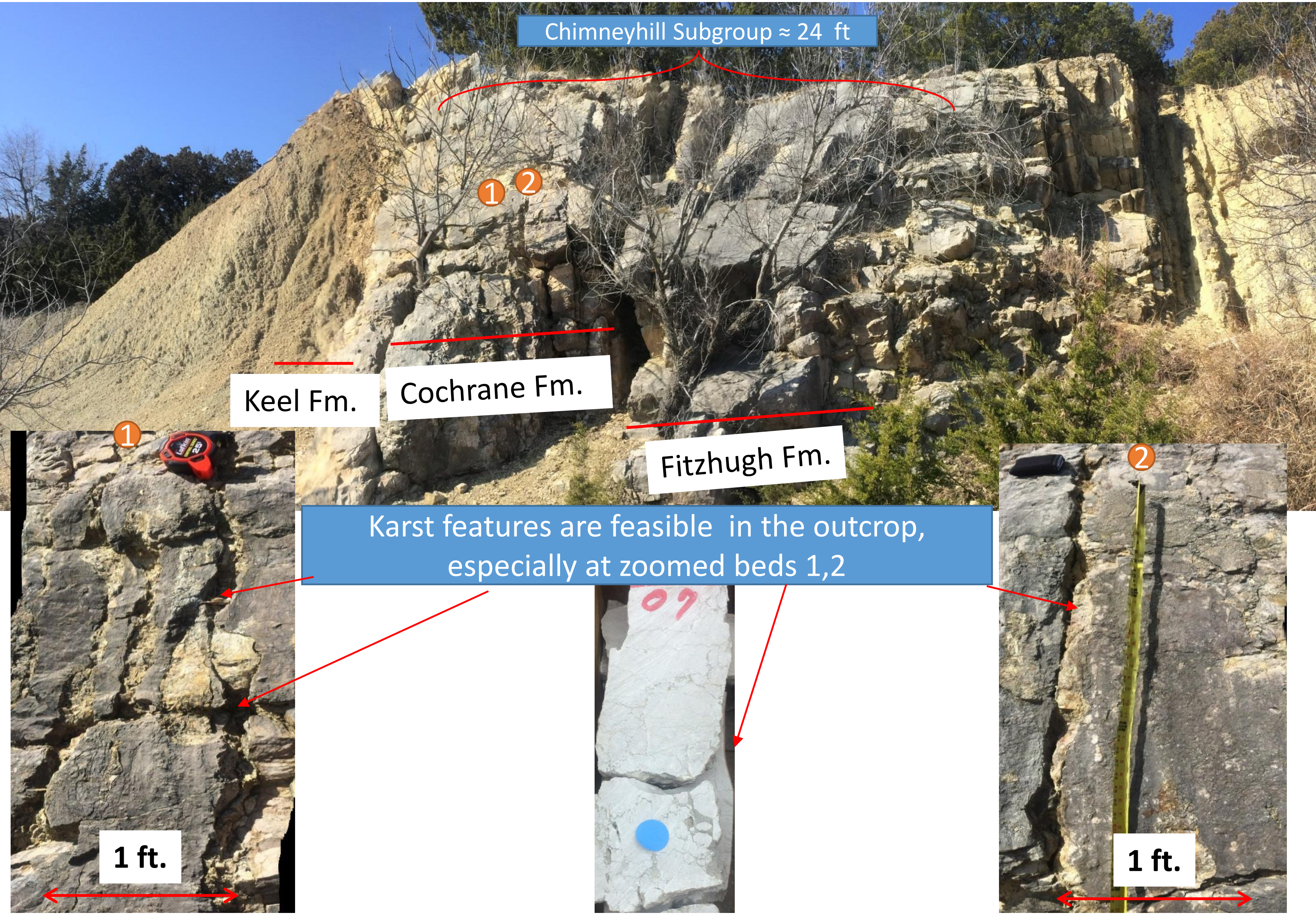
Vertical Fracture Intensity= (Total Fra length)/(area)= (7.1949/(3.64*1.83)=1.08 Fra/in


n=10,000
Histogram Showing the range of Fracture Width
Frequency
4000
3500
3000
2500
2000
1500
1000
500
0
Digitized Fractures
0.0098
0.0197
0.0295
0.0394
0.0787
0.0984
0.1181
0.1575
0.1969
Fracture aperture, in
n=205
Histogram Showing the range of Fracture Width
Frequency
50
40
30
20
10
0
Observed Fractures
0.0030
0.0039
0.0049
0.0059
0.0069
0.0089
0.0108
Fracture aperture, in
Observed vs Digitized Fractures
y = 0.0217x^0.4273
R² = 0.9917
Core Fractured Width (in)
0.012
0.01
0.008
0.006
0.004
0.002
0
0
0.05
0.1
0.15
0.2
0.25
Observed vs Digitized Fractures
Digitized Fractured Width (in)
n=10,000
Histogram Showing the range of Fracture Width
Frequency
4000
3500
3000
2500
2000
1500
1000
500
0
Corrected Fractures Width
0.0030
0.0041
0.0048
0.0054
0.0073
0.0081
0.0087
0.0098
0.0108
Fracture aperture, in

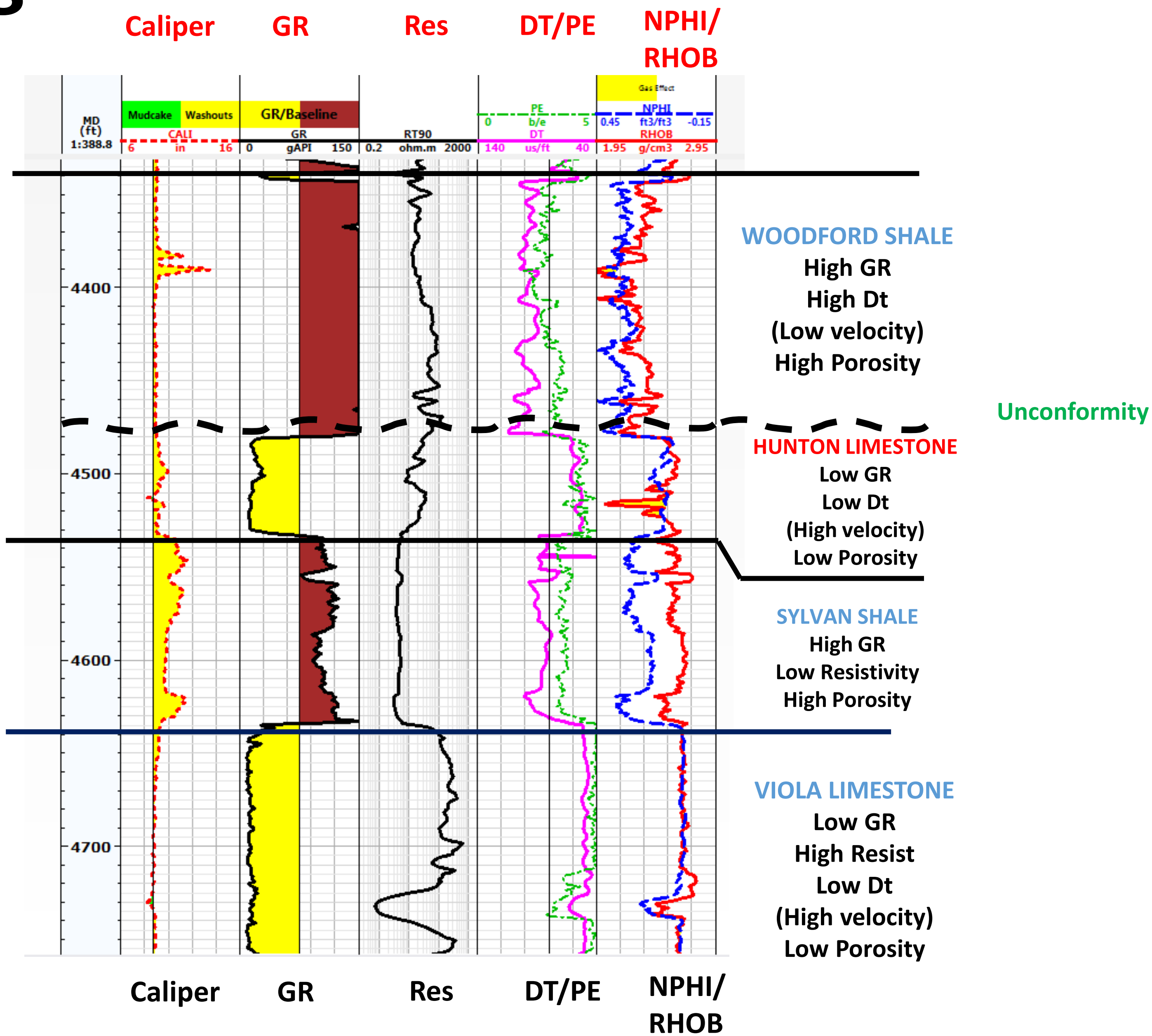


Lithology
Fossils
Pic
Total GR (API)
0 250 500
Hardness using MRH (HLD)
300 500 700 900
Porosity Core (%)
0 2 4
Permeability (md)
0 0.005 0.01
Butt Core
pyrite bed.
half inch of pyrite bed.
Styolite
coarse grain Crystal. Shiny view
SB
Brecciated Hunton
Woodford Shale
karsted Hunton
Non-karsted Hunton
Fracture density [fracture length (ft) /area (ft2)]
Orange lines are stylolite density [stylolite length (ft) /area (ft2)]
5285
5290
5295
5300
5305
5310
5315
5320
5325
5330
5335
5284.0
5286.0
5288.0
5289.6
5291.0
5292.8
5293.4
5295.0
5296.4
5297.4
5299.0
5300.3
5302.0
5303.3
5305.3
5307.0
5308.6
5310.0
5312.0
5314.0
5315.7
5317.0
5318.3
5320.0
5321.3
5322.7
5324.0
5324.9
5326.0
5327.5
5328.8
5329.8
5330.9
5331.8
Milad and Slatt (2017)

Outcrop Karst Features

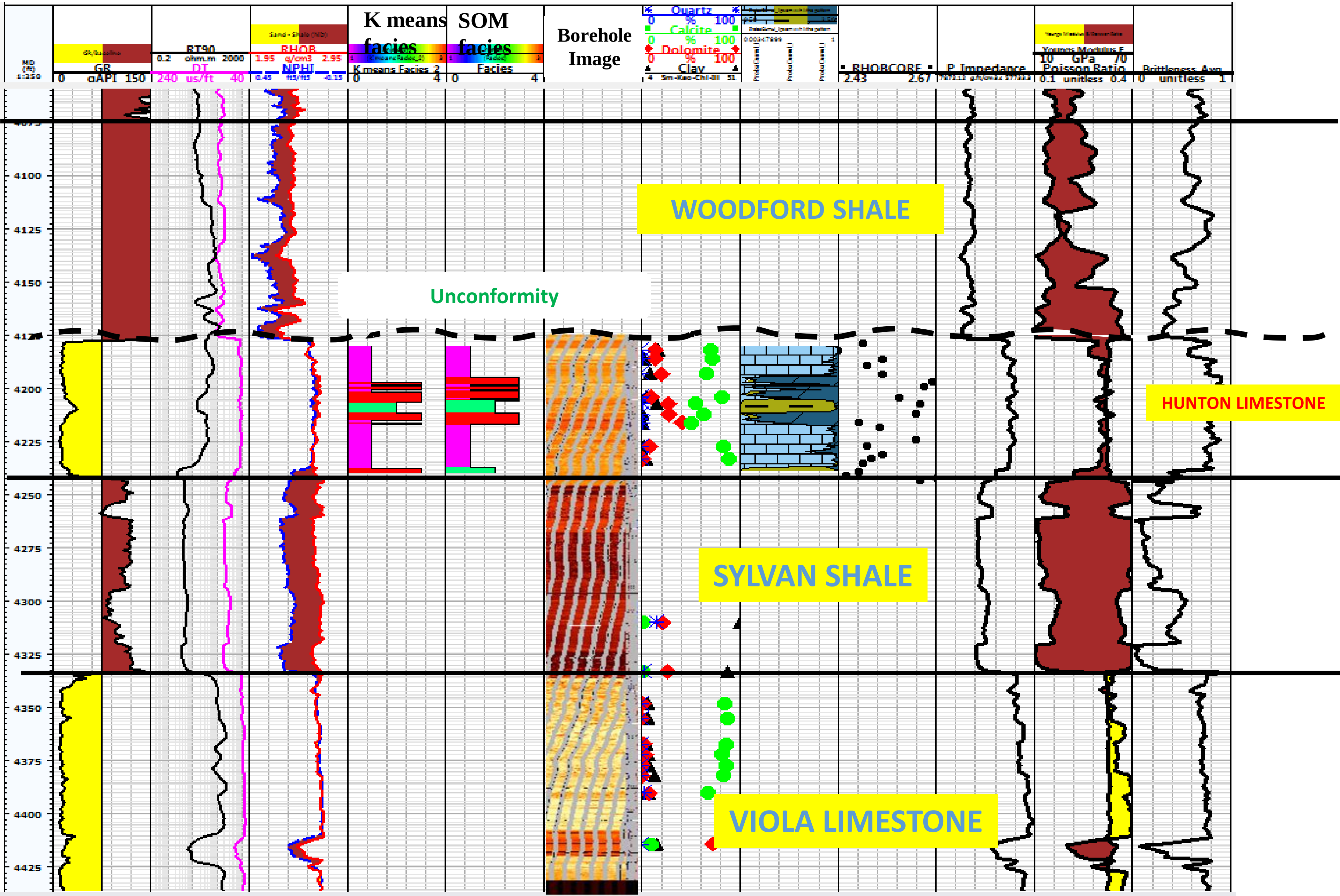


Type Log

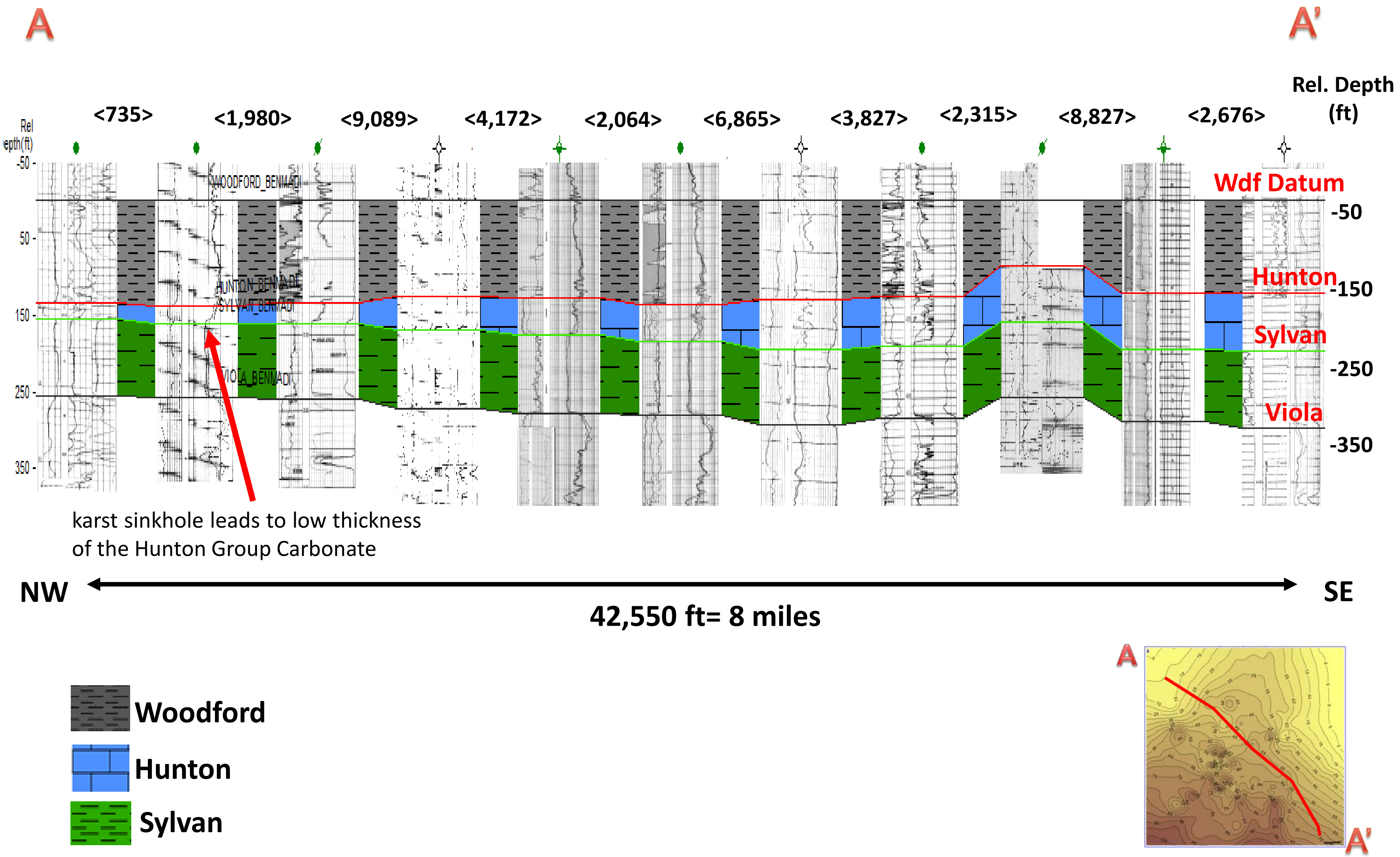


Caliper
GR
Res
DT/PE
NPHI/
RHOB
MD
(ft)
1:388.8
Mudcake
Washouts
GR/Baseline
CALI
6 in 16
GR
0 gAPI 150
RT90
0.2 ohm.m 2000
PE
0 b/e 5
DT
140 us/ft 40
Gas Effect
NPHI
0.45 ft3/ft3 -0.15
RHOB
1.95 g/cm3 2.95
4400
4500
4600
4700
WOODFORD SHALE
High GR
High Dt
(Low velocity)
High Porosity
Unconformity
HUNTON LIMESTONE
Low GR
Low Dt
(High velocity)
Low Porosity
SYLVAN SHALE
High GR
Low Resistivity
High Porosity
VIOLA LIMESTONE
Low GR
High Resist
Low Dt
(High velocity)
Low Porosity
Caliper
GR
Res
DT/PE
NPHI/
RHOB

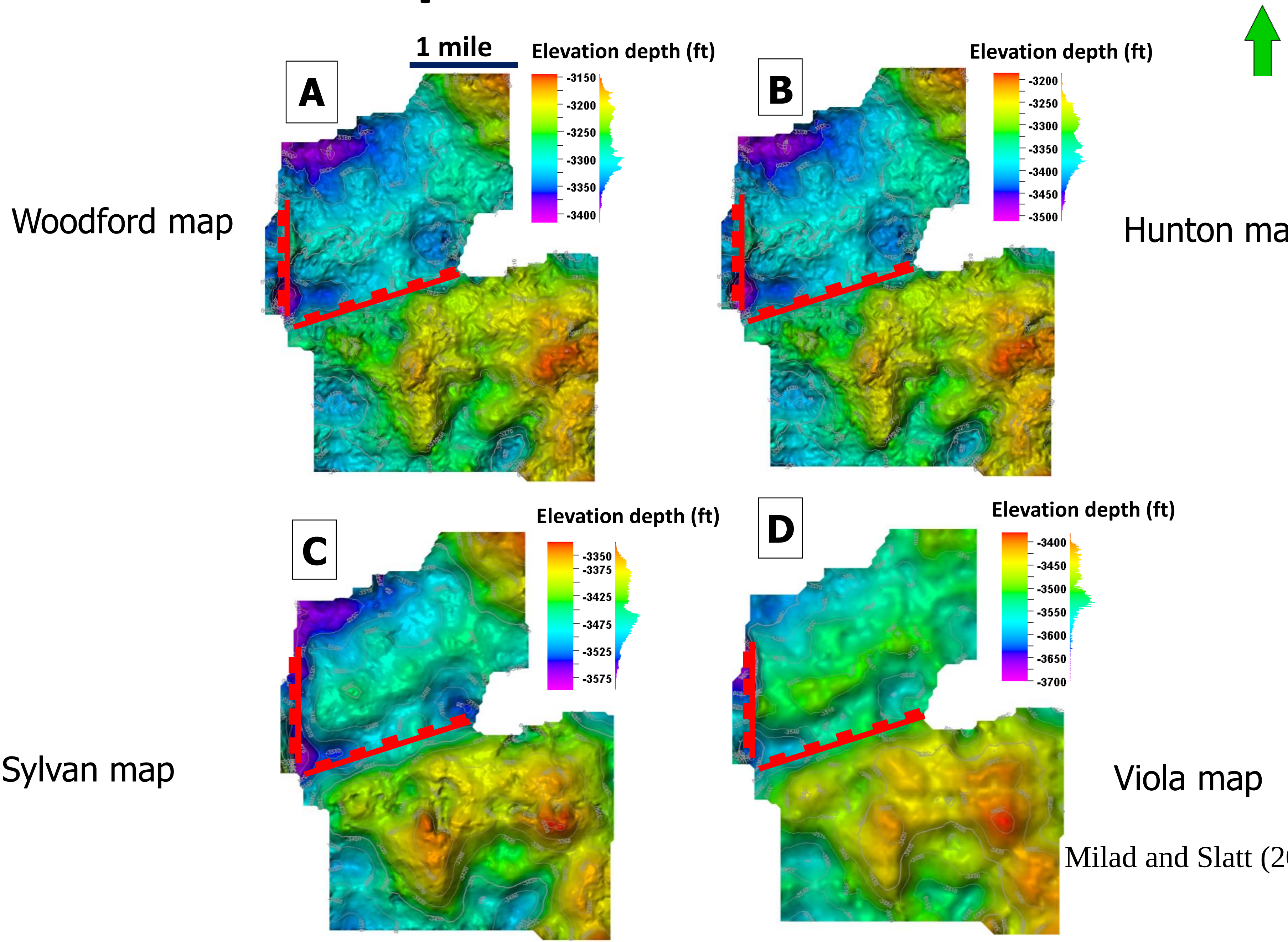
Poro-elastic properties of dynamic moduli



NW to SE Stratigraphic Cross Section

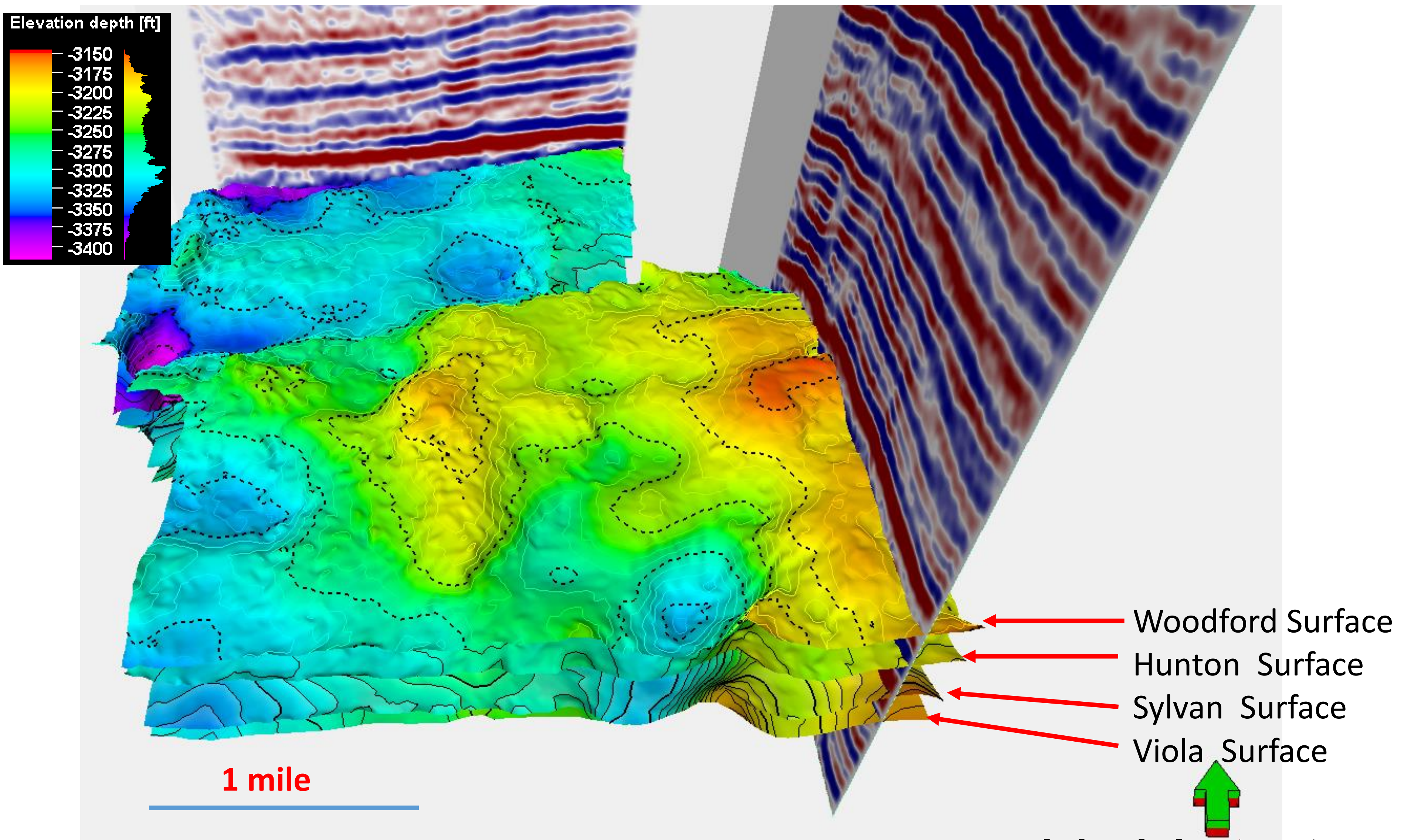


Structure maps



Milad and Slatt (2017)

Karst features from a 3D Seismic Volume



Milad and Slatt (2017)

Conclusions

1) Core fractures are related to the karstification processes.

2) Most fractures in the core occur in the karsted stratigraphic section where the rocks have high hardness values.

3) The karst features, such as sinkholes on the Hunton unconformity surface are prominent factors controlling the paleotopography and deposition of the Woodford Shale.

4) Sinkhole features range in diameter from 1150 to 2300 ft. and extend vertically to almost 300 ft. Sinkholes can be a sweet spot for the Woodford Shale to be drilled.

5) The brittleness index from well logs can be used as a proxy to target a zone for hydraulic fracturing through the Viola Carbonate, Sylvan Shale, Hunton Group Carbonate, and the Woodford Shale.

References

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- Northcutt, R. A., 2002, History of Hunton Oil and Gas Exploration and Development in Oklahoma: Shale Shaker, p. 149-158.

Acknowledgments

- **Dr. Roger M. Slatt**
- **Dr. Kurt Marfurt**
- **Institute of Reservoir Characterization**
- **Woodford Shale Consortium**
- **Pathfinder Exploration**

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Phase III consortium members