Identifying Hazards and Enhancing Reservoir Models Through Interpretation of Hyperspectral Core Imaging in Unconventional Plays*

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Search and Discovery Article #80675 (2019)**
Posted April 1, 2019

*Adapted from oral presentation given at 2018 International Conference and Exhibition, Cape Town, South Africa, November 4-7, 2018
 DOI:10.1306/80675Hollon2019

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Abstract

Hyperspectral core imaging is a non-destructive, infrared-wavelength technology traditionally used by mining operators as a method of identifying key lithological facies and mineral textures and alterations. An emerging technology with respect to Oil/Gas exploration, when integrated with traditional lab analyses and petrophysical methods hyperspectral core imaging will refine interpretations to accurately identify drilling and completion hazard as well as reservoir and fracture propagation models. Incorporating additional lab analyses such as X-ray diffraction, porosity/permeability analysis, rock mechanics, organic geochemistry, and thin sections interpretation along with hyperspectral imaging can clarify previously tenuous evaluations associated with well log responses in unconventional shale or carbonate plays. By providing high-resolution images of mineralogy in relation to depositional fabric and textures within continuous conventional core, hyperspectral imaging allows for a more inclusive, cohesive grouping and correlation between log-derived electrofacies and sedimentological facies. Strengthening this correlation will increase the capacity to identify drilling and fracking hazards that can cause costly rig delays, including well instability and bit-deviation. Differential cemented facies, recrystallized bedding or the widespread occurrence of expandable smectite are all common origins of drilling and fracking risks that can be better understood and mitigated by integrating hyperspectral imaging with traditional energy exploration techniques. Hyperspectral imaging is invaluable when developing models to characterize specific lithology packages. In turn, these packages are used to identify potential horizontal landing zones, hydrocarbon pay zones, drilling and completion hazards (borehole stability, and fracking hazards) and flow

barriers, ultimately reducing cost and increasing production. For example, hyperspectrally-defined lithological packages combined with density and resistivity logs can reveal potential flow barriers that in other wells had remained undetected. Hydrocarbon pay zones can be defined by the lithological packages where hydrocarbons and hydrocarbons enmeshed with other minerals are detected by hyperspectral imaging. This same method of classification is used to evaluate cores in producing wells for behind the pipe pay to be further pursued or to validate new calculations of reserve estimations.

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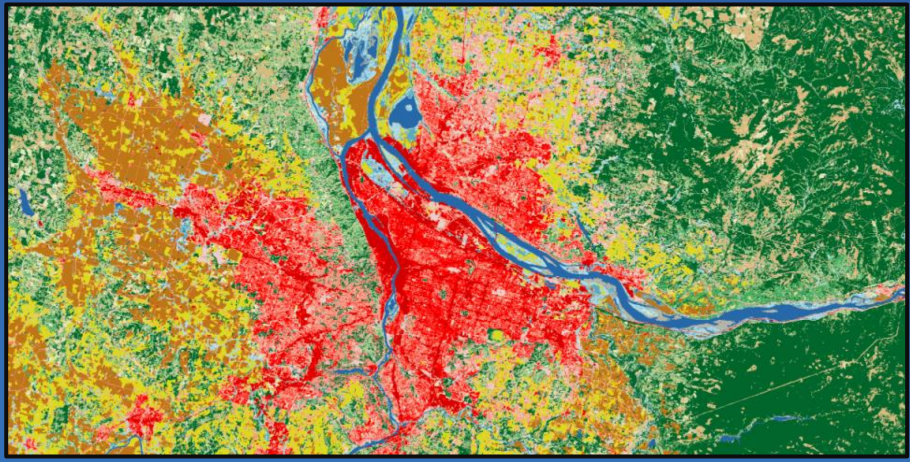
Outline

- Hyperspectral Core Imaging Overview
- Calibrating with Lab Data
- Predicting Drilling and Fracking Hazards
- Identifying Missed Pay in Old Core

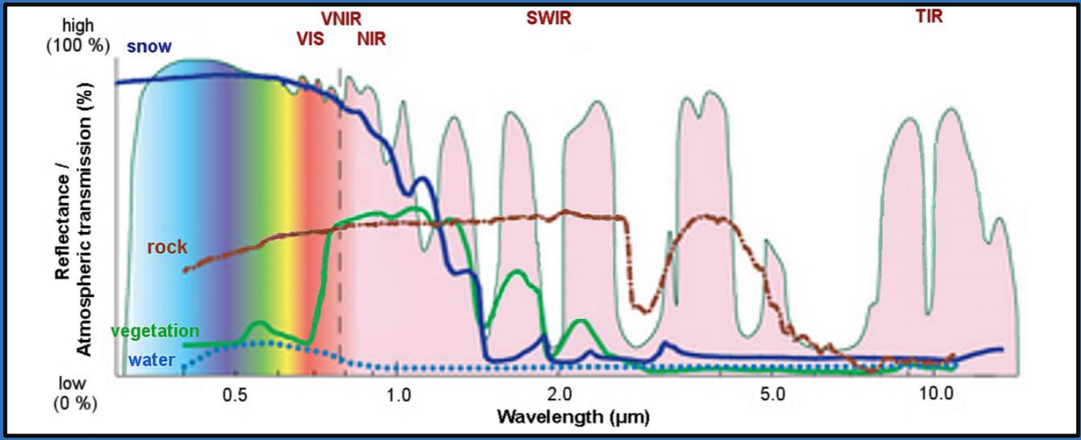
Hyperspectral Core Imaging Overview

Background

- Developed from LIDAR technology
- Used by oil and gas prospectors since the 1970s
- Common in mining industry for aerial mapping and outcrop/mine face studies
- Measures subsets of the electromagnetic spectrum
  - ➢ visible near-infrared (VNIR)
  - ➢ short-wave infrared (SWIR)
  - ➢ thermal infrared (TIR)



NASA, 2015



Egbers, 2016

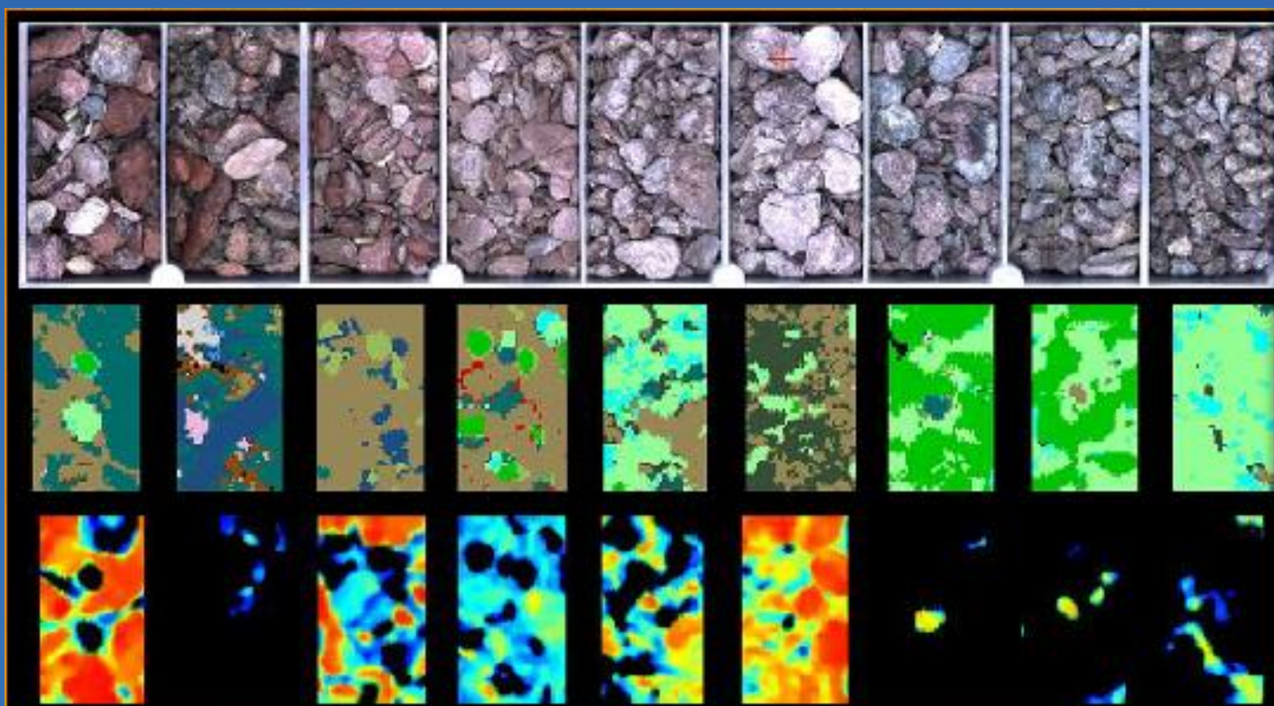
Hyperspectral Core Imaging

- Non-destructive
- Minimal sample prep (needs to be dry)
- Automated data collection
- Can analyze core/plugs/cuttings
- Can detect up to 8 mineral per pixel

Approximately 200,000 spectra/pixel per meter scanned

Scan rates vary from 200–1000 meters per day depending upon operational constraints

- Spectral pixel resolution down to 0.5mm (coarse sand grain size)
- 3D laser profiling providing RGB & textural resolution down to 20µm (clay-size sediments)



RGB Photography

Mineral Classification Maps

Mineral Abundance Maps

Kaolinite Abundance

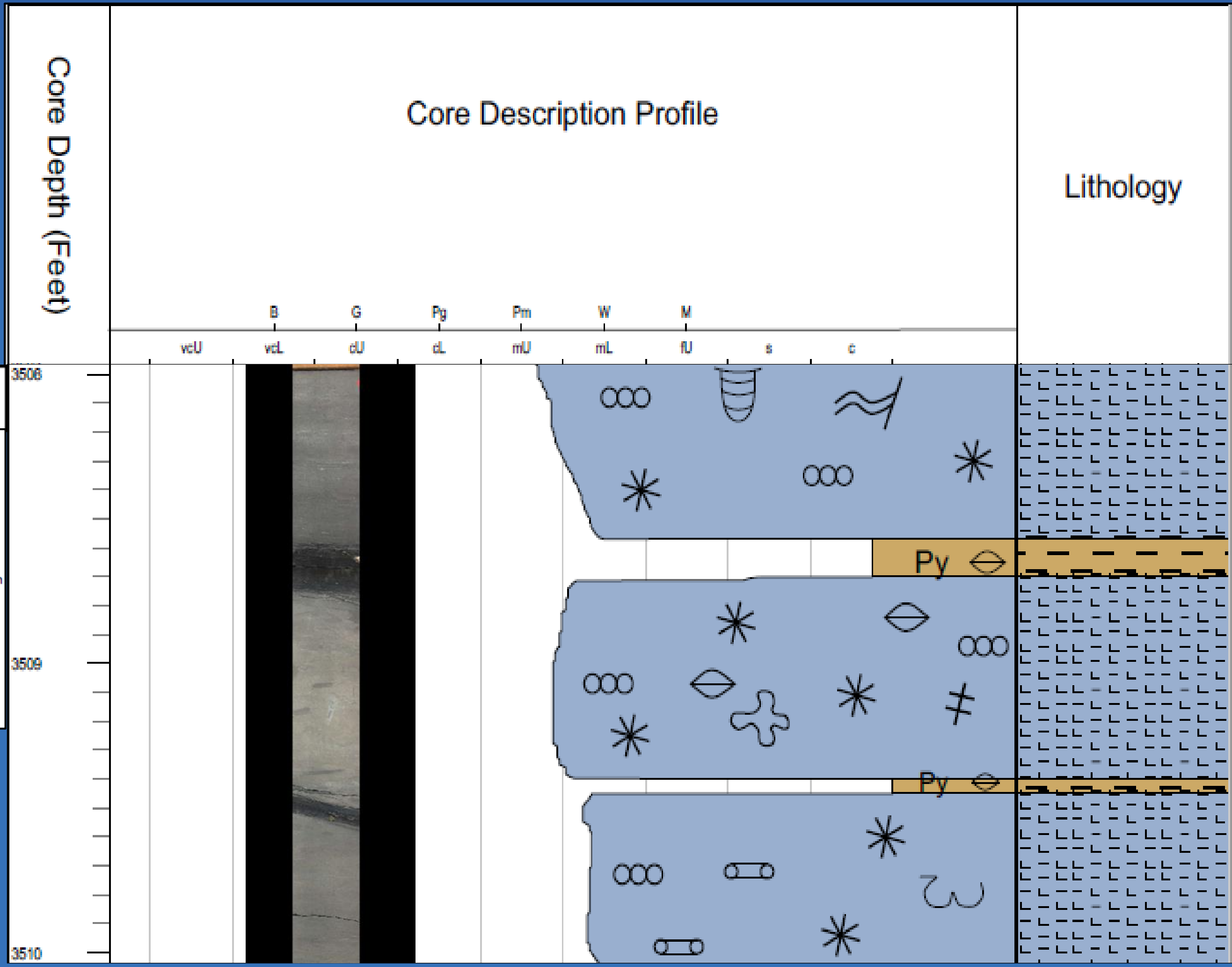
Proprietary; Screencap from Coreshed.com

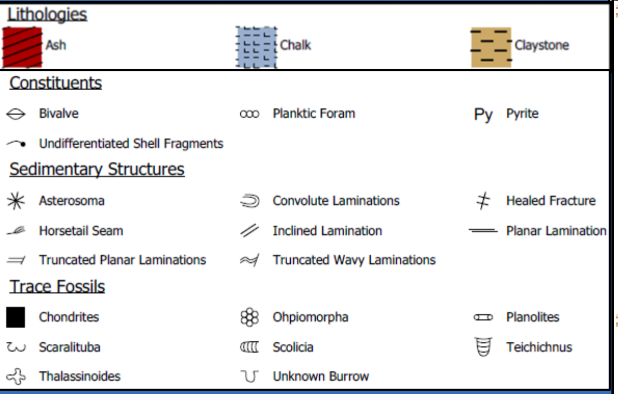
coreScan

Calibrating with Lab Data

Austin Chalk, Cretaceous Maverick Basin Unconventional Reservoir

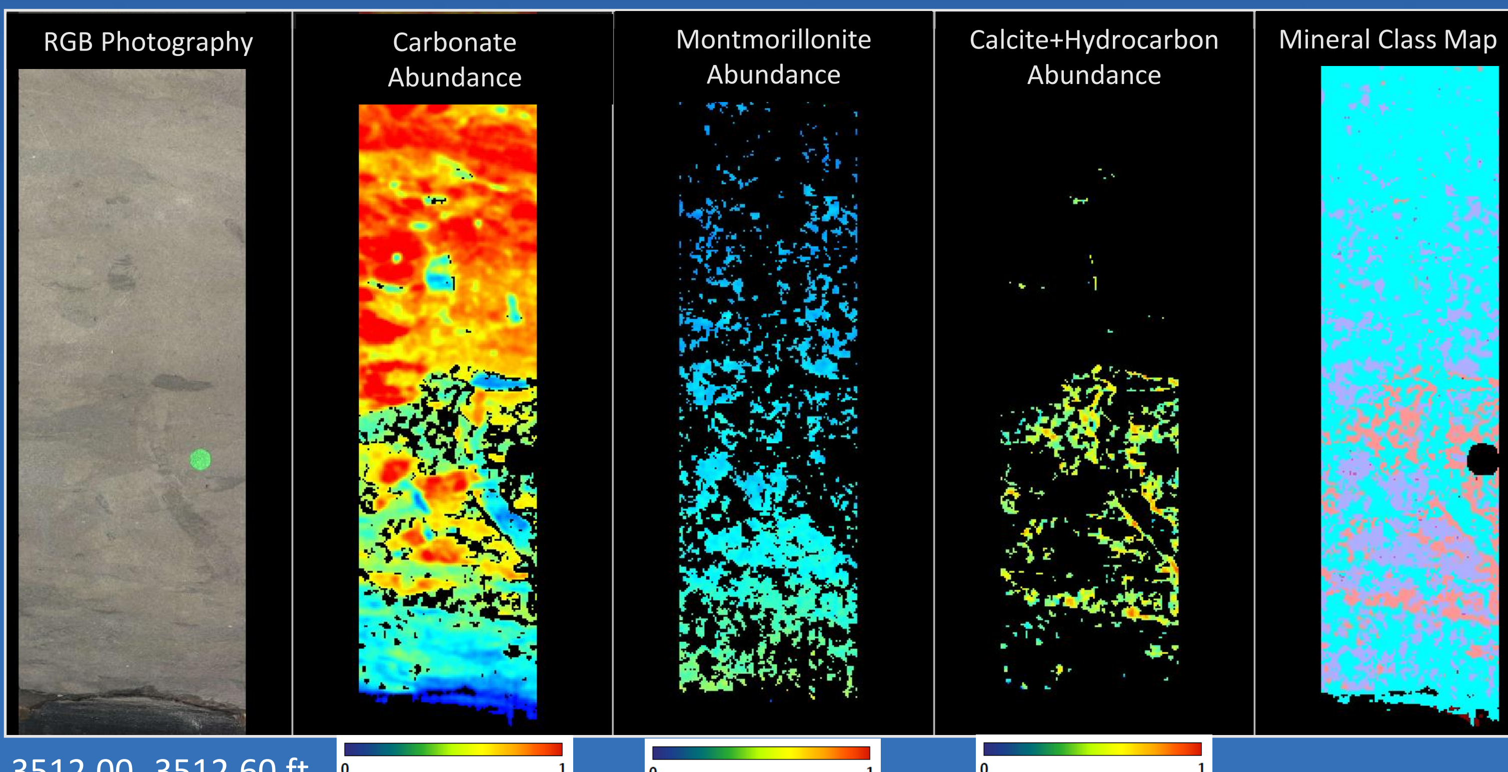
3508.00-3510.00 ft.





Scale
1:24

Austin Chalk
Hyperspectral Mineral Maps



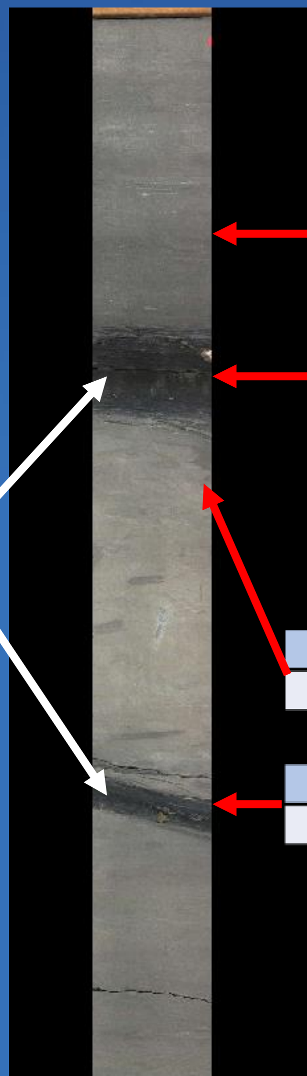
3512.00 -3512.60 ft.

Mineral Name	Color
Calcite	
Calcite + Hydro	
Gypsum	
Hydrocarbon	
Montmorillonite	
Aspectral	
Ferrous Mineral	
Iron Oxide	
Kaolinite	

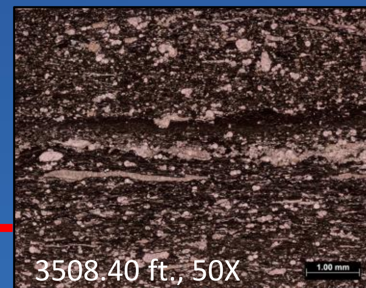
Screencap from Coreshed.com

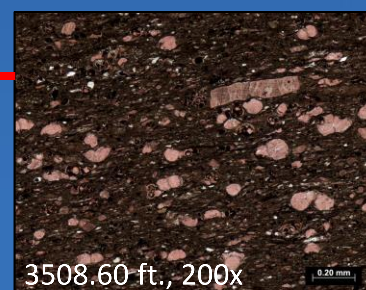
Calibration of lithological facies using additional lab-derived data in combination with mineral maps

Intervals that are too fine grained or with high reflectance use RGB photography to build lithology models



3508.00-3510.00 ft.





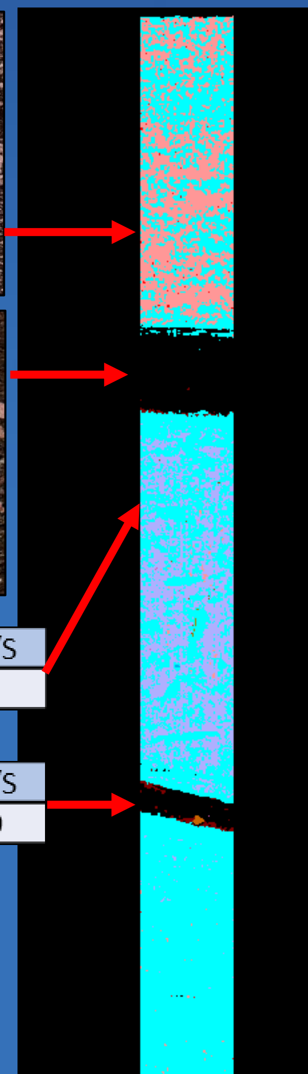
Calcite	Illite/Mica	Mx I/S
97.2	1.0	0.8

3508.95 ft.

Calcite	Illite/Mica	Mx I/S
34.4	4.8	29.0

TOC (wt%)
2.73

3509.40 ft.

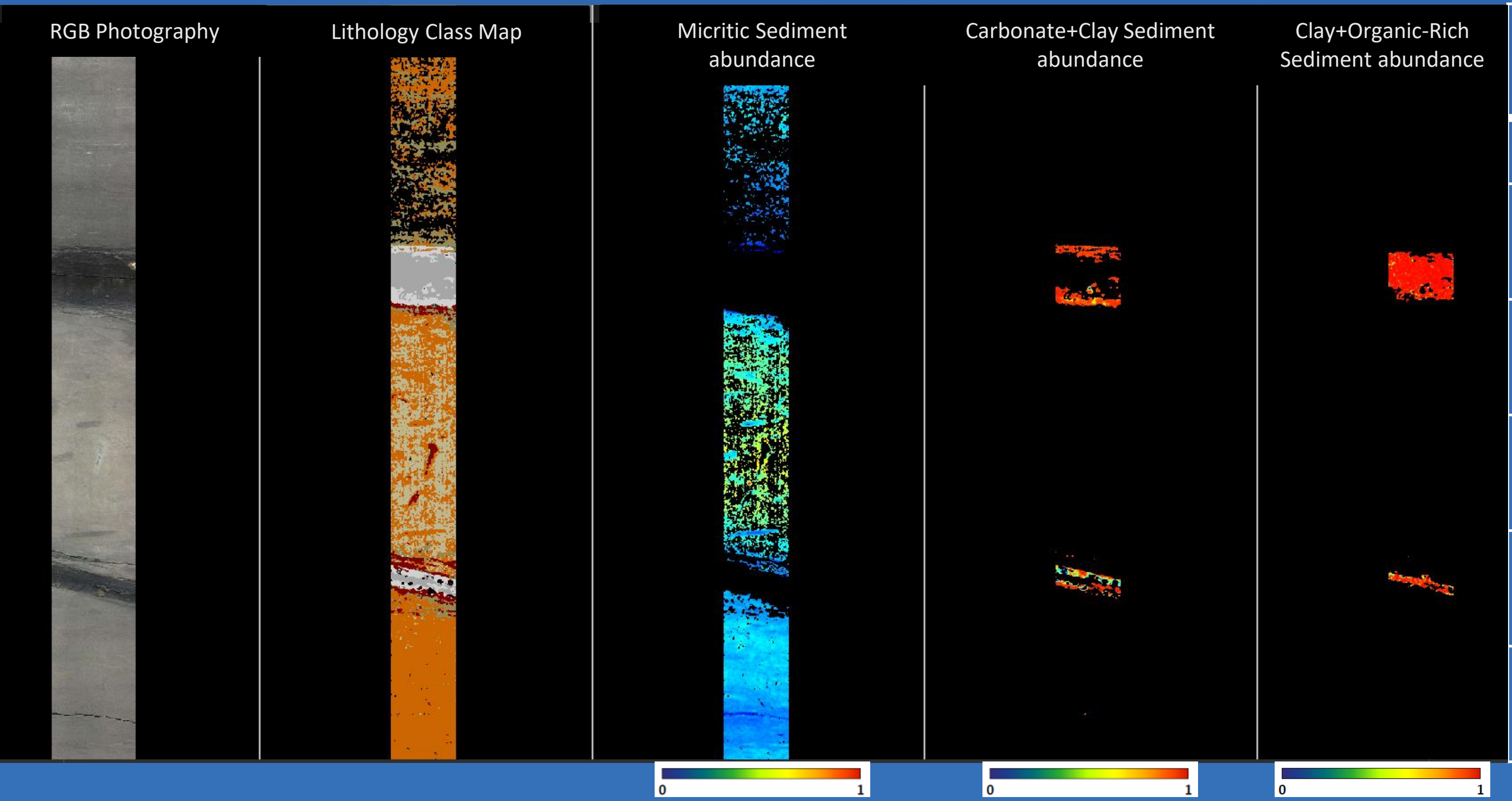


Mineral	Color
Calcite	
Calcite+ Hydrocarbons	
Gypsum	
Hydrocarbon	
Montmorillonite	
Aspectral	
Ferrous Mineral	
Pyrite	
Kaolinite	

Screencap from Coreshed.com

Lithology Maps

- The lithology class map below was created using thin section, XRD, and TOC data.
- The lithologies can be counted by pixel to create semi-quantitative volumes and used to calibrate well logs.



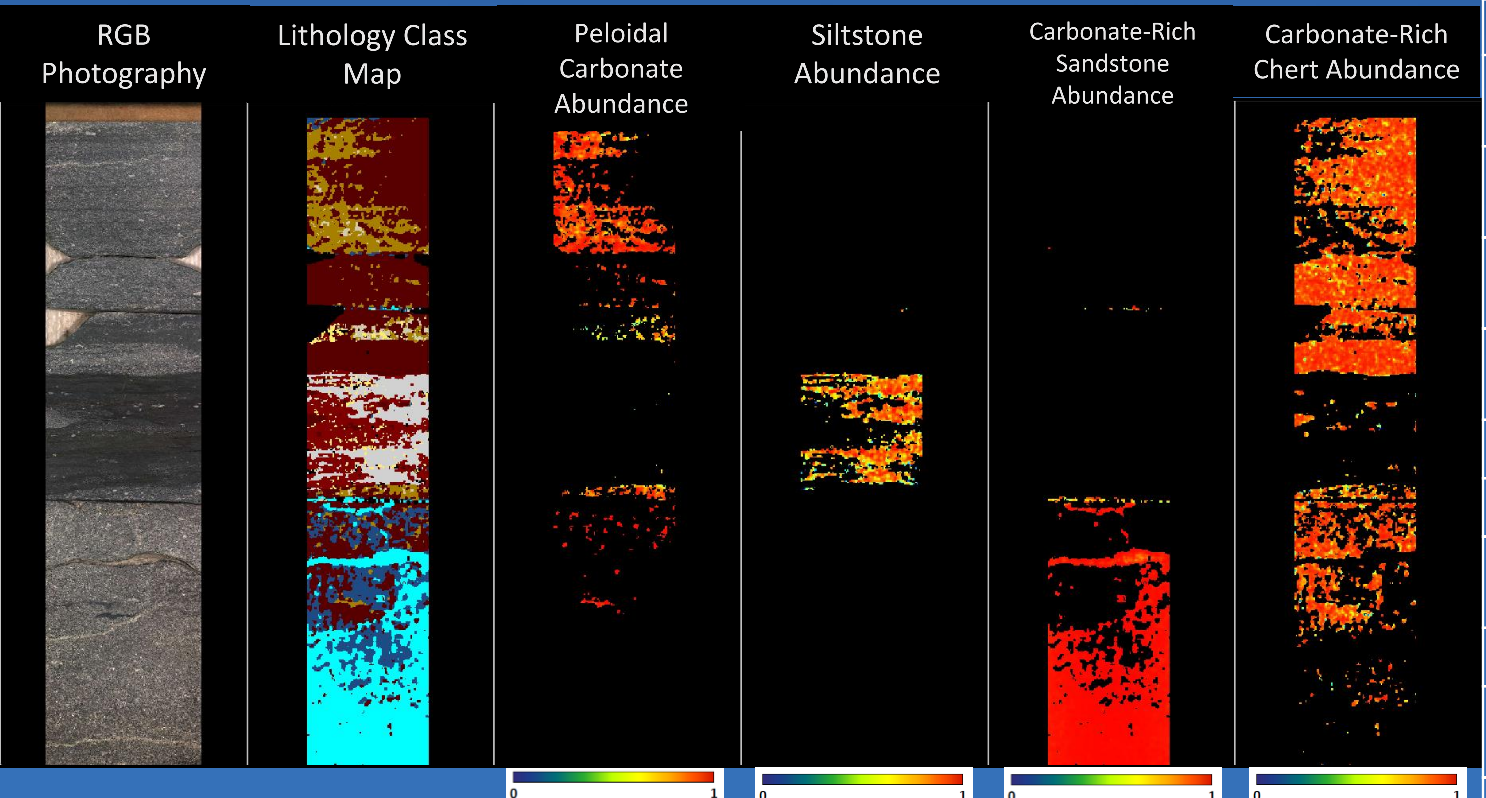
Lithology	Color
Micritic Sediment	
Fine Fossiliferous Sediment	
Clay+Organic-Rich Sediment	
Carbonate+Clay Sediment	
Coarse Fossiliferous Sediment	
Disseminated Clay Sediment	

Screencap from Coreshed.com

Predicative Applications: Identification of Drilling and Fracking Hazards

Example 1: Drilling delays due to chert-rich lithology

Oklahoma Mississippian unconventional reservoir
Mixed-clastics and carbonate
Can have localized biogenic silica and chert beds



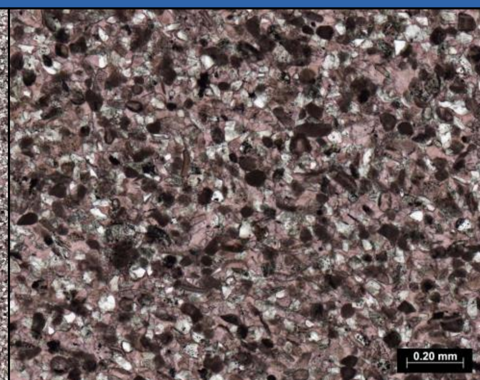
Lithology	Color
Micritic Mudstone	
Carbonate-rich Claystone	
Carbonate-rich Siltstone	
Carbonate-rich Sandstone	
Peloidal Carbonate-rich Sediment	
Chert	
Carbonate-rich Chert	
Argillaceous, Silty Mudstone	
Claystone	
Undifferentiated Mudstone	
Siltstone	

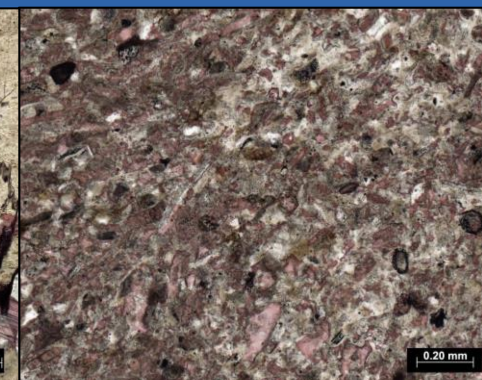
Damages Drill Bit

Screencap from Coreshed.com

Lithology Maps tied with thin section analysis create composite logs to identify chert and carbonate-chert problem intervals

Damages Drill Bit

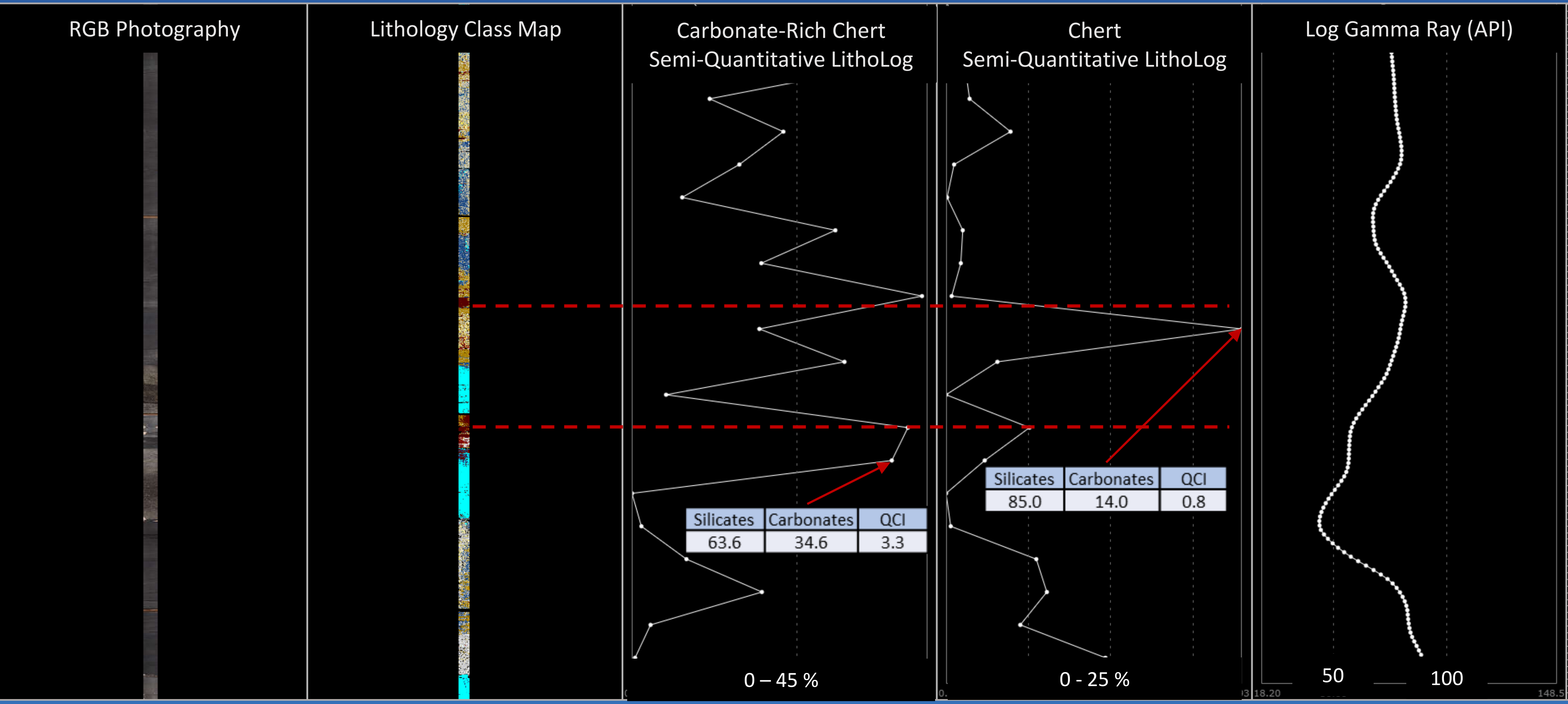




Carbonaceous Sandstone (50X)	Peloidal Carbonaceous Sediment (200x)	Chert (50X)	Carbonaceous Chert (200X)
2.170	3.087	0.091	7.673
1.440	26.916	1.528	30.993
2.142	14.442	1.349	19.725
0.598	39.533	0.509	43.971
0.000	16.548	30.169	21.641
23.206	25.406	4.723	32.547
89.313	0.000	0.000	5.195
3.183	37.452	7.672	42.231
32.768	4.553	3.525	39.444
96.832	0.000	0.000	0.036
30.113	0.245	0.458	1.576
0.175	6.913	8.901	8.972
0.035	22.035	9.472	20.339
0.203	28.970	6.795	2.862
0.369	1.674	14.859	0.516
93.670	0.000	0.375	1.384

Pixel count per depth interval

XRD-generated quartz crystallinity index numbers support the hyperspectral chert lithologies



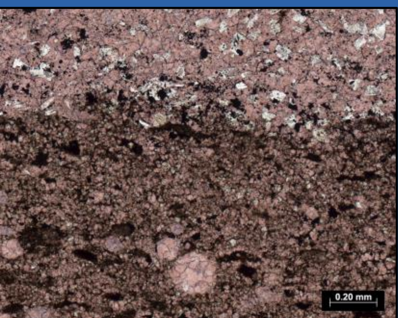
Screencap from Coreshed.com

Quartz Crystallinity Index (QCI) is a unitless index ranging from 0 (chert) to 10 (highly-ordered quartz) measured using X-ray diffraction

Example 2: Diagenetic frac barriers in the Eagle Ford shale

Recrystallized limestone beds and altered volcanic ash cause frac collapse and wellbore instability

3945.20 ft., 200X

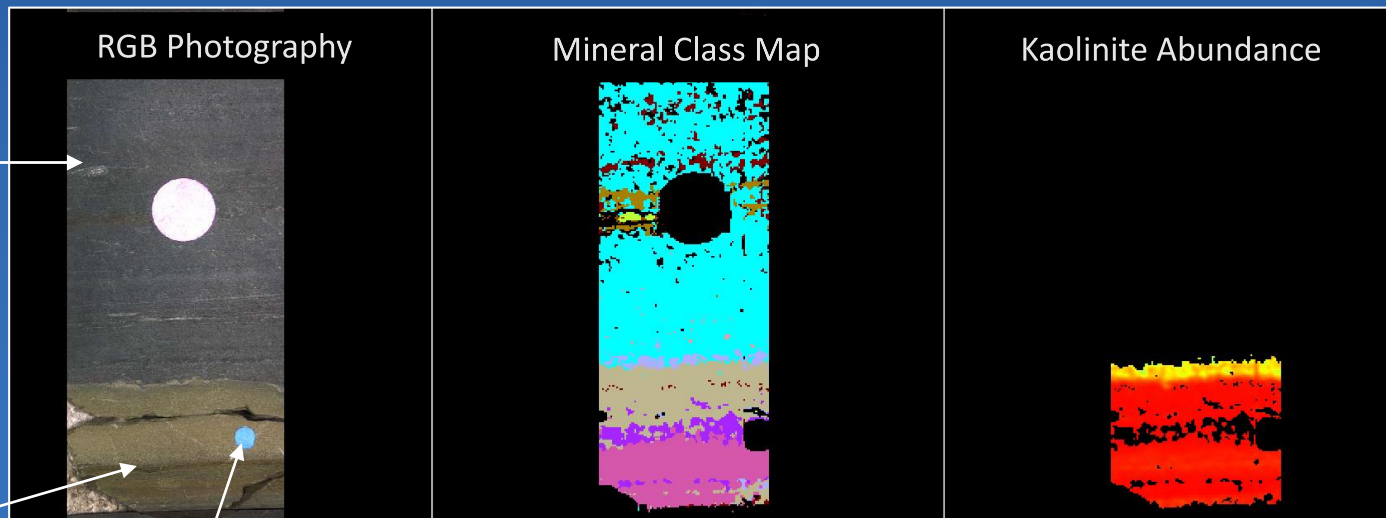


Recrystallized limestone with altered feldspars

3945.40 ft., 50X

Thin sections and XRD confirm presence of volcanic-origin clays

3945.00 - 3945.50 ft.

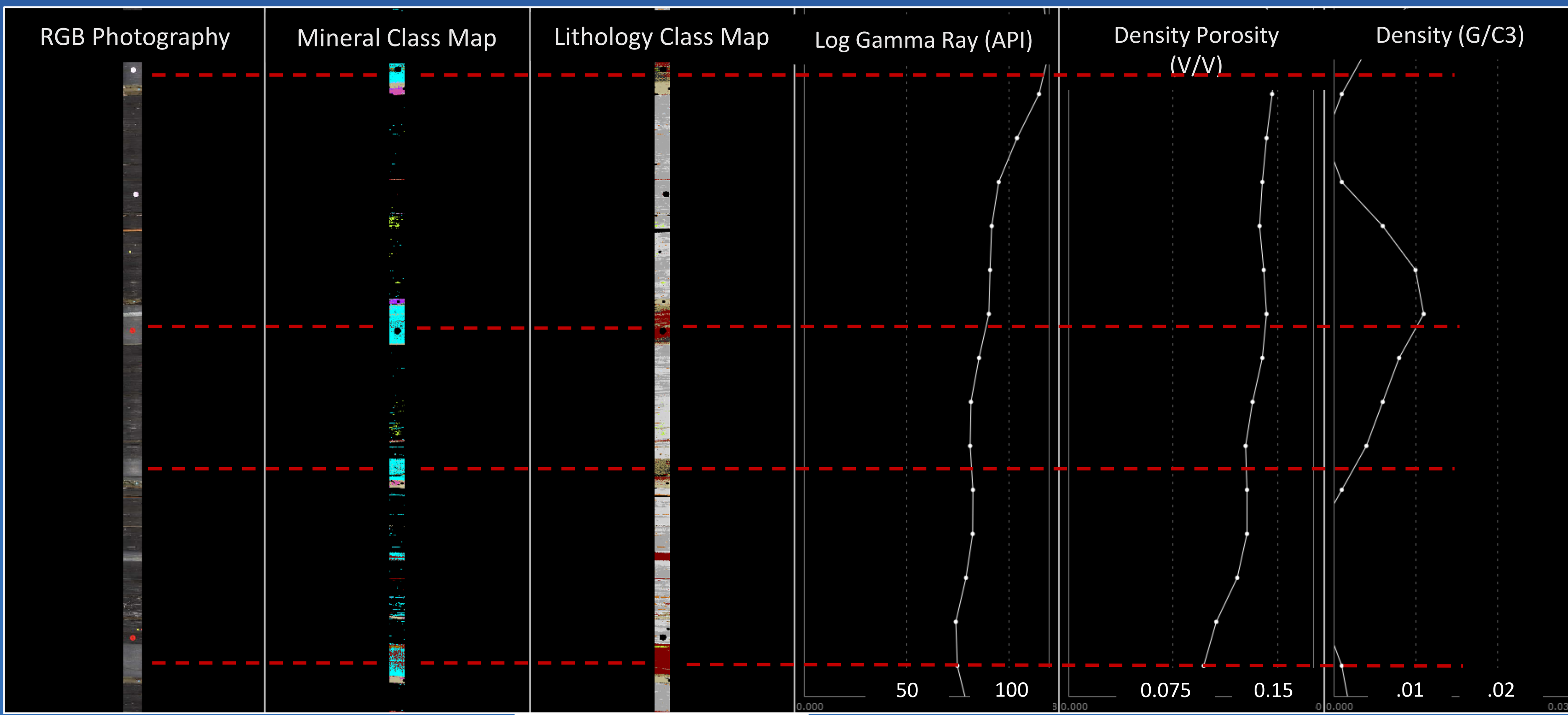


Kaolinite	Illite/Mica	Mx I/S	Rectorite
2.3	5.9	55.2	0.9

Mineral	Color
Calcite	
Gypsum	
Buddingtonite + Smectite	
Montmorillonite	
Aspectral	
Ferrous Mineral	
Kaolinite	

Screencap from Coreshed.com

Location of flow barriers within the Eagle Ford shale compared to well logs



3945.00 - 3952.00 ft

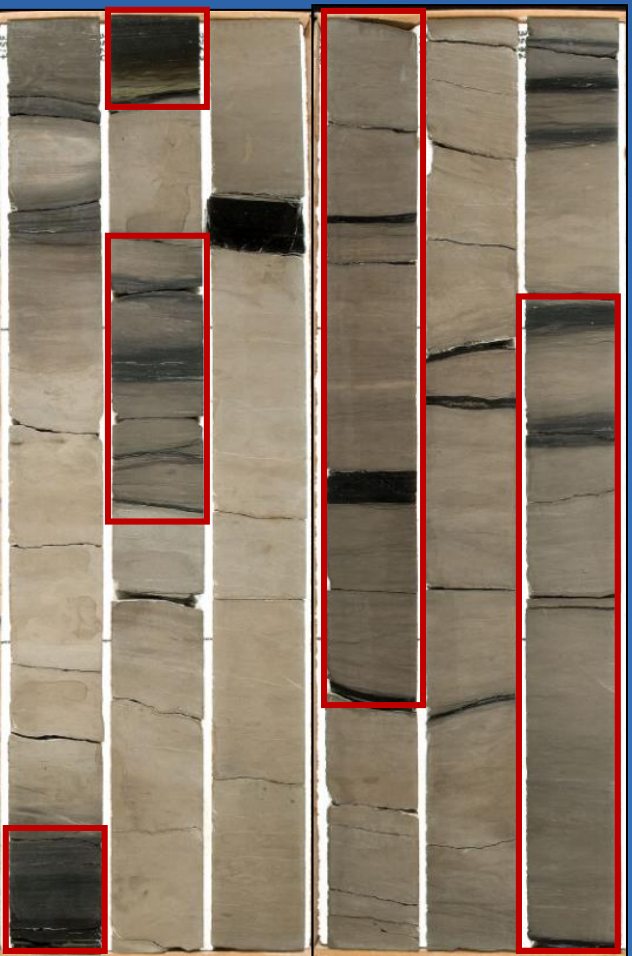
Lithology	Color
Fine Fossiliferous Sediment	
Coarse Fossiliferous Sediment	

Screencap from Coreshed.com

Missed Pay: Reassessing Old Core for New Opportunities

Austin Chalk – Example of Missed pay (sample bias)

White Light Core Photography circa 2011



3517.00 – 3534.00 ft.

- Originally cored in 2005 in Maverick County
- Common knowledge at the time was the best reservoir was found in the argillaceous chalk
- Sampling intervals for thin sections, XRF, XRD, and TOC were selected based upon white light core photography

Example of lithology that was not sampled in the original project

White Light Core Photography

“Clean” chalk lithology – not the assumed reservoir lithotype

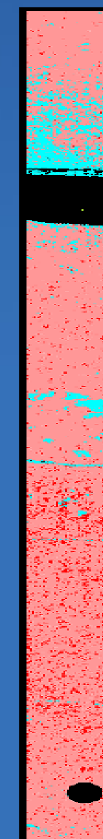
3523.00 – 3526.00 ft.

UV Core Photography

Slight fluorescence, but unable to determine whether caused by hydrocarbons or differential mineral fluorescence

Hyperspectral images collected in 2017 (12 years after coring) identifies hydrocarbons

Mineral Class Map



3523.00 – 3526.00 ft.

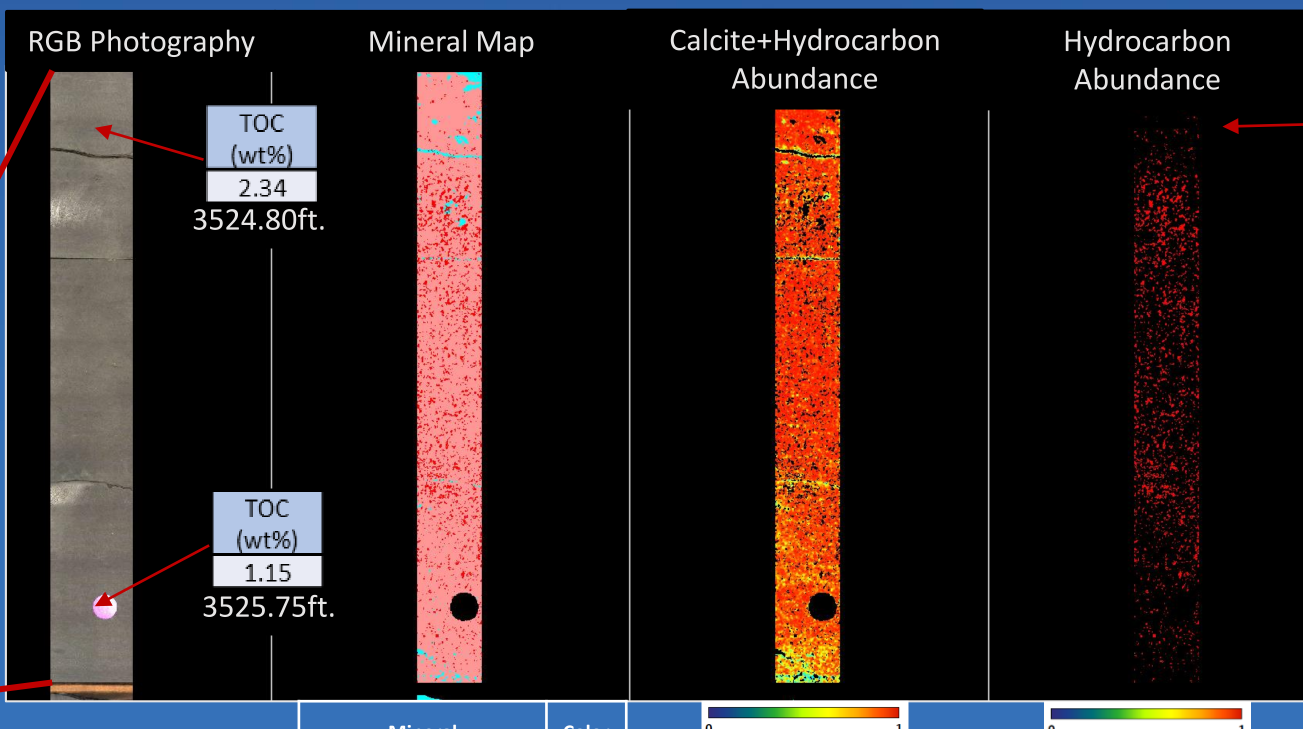
Mineral	Color
Calcite	
Calcite+Hydrocarbons	
Gypsum	
Hydrocarbon	
Montmorillonite	
Aspectral	
Ferrous Mineral	
Pyrite	
Kaolinite	

Screencap from Coreshed.com

Samples chosen based upon hyperspectral data show correlation in mineralogy, fabric, and potential TOC

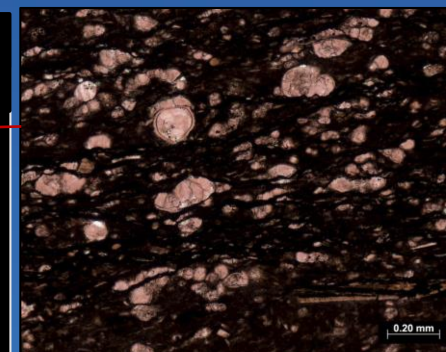
3524.50 - 3526.00 ft.

2011



2017

Mineral	Color
Calcite	
Calcite+Hydrocarbons	
Hydrocarbon	



3524.80 ft., 200X

Organic material is heavily intermixed with micritic matrix

Screencap from Coreshed.com

Conclusions

Hyperspectral core imaging complements lab analyses by showing features and mineralogy overlooked by most traditional lab procedures

Hyperspectrally-derived mineral and lithology map logs calibrated by the appropriate lab analyses can assist in evaluating drilling and fracking hazards

Reassessment of older unconventional cores with hyperspectral imaging technology can reveal organic-rich lithological facies unnoticed by previous prospects

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