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

Brittany Hollon¹, Haleigh Howe¹, P.F. DuBois¹, Lionel Fonteneau², and Brigette A. Martini³

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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)

Egbers, 2016

NASA, 2015
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)
Calibrating with Lab Data
Austin Chalk, Cretaceous Maverick Basin
Unconventional Reservoir

Lithologies
- Ash
- Chalk
- Claystone

Constituents
- Bivalve
- Planktic Foraminifera
- Pyrite

Sedimentary Structures
- Asterommina
- Convolute Laminations
- Healed Fracture
- Inclined Lamination
- Planar Lamination

Truncated Planar Laminations
- Truncation Wavy Laminations

Trace Fossils
- Chondrites
- Ophiomorpha
- Planolites
- Scutella
- Sterechinus
- Thalassinoides
- Unknown Burrow

Core Depth (Feet)
- 3508.00-3510.00 ft.

Scale
1:24
Austin Chalk
Hyperspectral Mineral Maps

3512.00 - 3512.60 ft.

RGB Photography
Carbonate Abundance
Montmorillonite Abundance
Calcite + Hydrocarbon Abundance
Mineral Class Map

<table>
<thead>
<tr>
<th>Mineral Name</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcite</td>
<td></td>
</tr>
<tr>
<td>Calcite + Hydro</td>
<td></td>
</tr>
<tr>
<td>Gypsum</td>
<td></td>
</tr>
<tr>
<td>Hydrocarbon</td>
<td></td>
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<tr>
<td>Montmorillonite</td>
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<tr>
<td>Aspectral</td>
<td></td>
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<tr>
<td>Ferrous Mineral</td>
<td></td>
</tr>
<tr>
<td>Iron Oxide</td>
<td></td>
</tr>
<tr>
<td>Kaolinite</td>
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</tbody>
</table>
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.

<table>
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<tbody>
<tr>
<td>Calcite</td>
<td>⬆️</td>
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<tr>
<td>Calcite+ Hydrocarbons</td>
<td>🟥</td>
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<tr>
<td>Gypsum</td>
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</tr>
<tr>
<td>Hydrocarbon</td>
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<tr>
<td>Montmorillonite</td>
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<tr>
<td>Aspectral</td>
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<tr>
<td>Ferrous Mineral</td>
<td>🟤</td>
</tr>
<tr>
<td>Pyrite</td>
<td>🟦</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>🟤</td>
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</table>
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.
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 Maps tied with thin section analysis create composite logs to identify chert and carbonate-chert problem intervals.
XRD-generated quartz crystallinity index numbers support the hyperspectral chert lithologies

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.

Recrystallized limestone with altered feldspars

Thin sections and XRD confirm presence of volcanic-origin clays

3945.00 - 3945.50 ft.

RGB Photography

Mineral Class Map

Kaolinite Abundance

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<tr>
<td>Calcite</td>
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Mineral Class Map:
- **Calcite**
- **Gypsum**
- **Buddingtonite + Smectite**
- **Montmorillonite**
- **Aspectral**
- **Ferrous Mineral**
- **Kaolinite**

Kaolinite Abundance:
- **3945.00 - 3945.50 ft.**
  - 3945.20 ft., 200X
  - 3945.40 ft., 50X

Screencap from Coreshed.com
Location of flow barriers within the Eagle Ford shale compared to well logs

Lithology

<table>
<thead>
<tr>
<th>Color</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Fossiliferous Sediment</td>
<td>Light Brown</td>
</tr>
<tr>
<td>Coarse Fossiliferous Sediment</td>
<td>Dark Red</td>
</tr>
</tbody>
</table>

3945.00 - 3952.00 ft
Missed Pay: Reassessing Old Core for New Opportunities
Austin Chalk – Example of Missed pay (sample bias)

- 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

UV Core Photography

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

Mineral Class Map

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

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3523.00 – 3526.00 ft.
Samples chosen based upon hyperspectral data show correlation in mineralogy, fabric, and potential TOC.

3524.50 - 3526.00 ft.

Organic material is heavily intermixed with micritic matrix.
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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