Quantitative Calibration of Hyperspectral Core Imaging Data: A New Method for Producing Continuous, High-Resolution Mineralogical Characterization of Cores from both Conventional and Unconventional Reservoirs

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CORESOLUTION TECHNOLOGIES

TERRACORE GEOSPECTRAL IMAGING

BACKGROUND

- Heterogeneity within oil and gas reservoirs can present challenges during lithological and flow unit characterization and upscaling

- Unconventional resources in particular:
    - Thin beds and laminae can be missed by wireline logging
    - Mineralogical and organic variations are subjectively difficult or impossible to define visually in core
    - Potential disconnect when upscaling micro and nano scale, discrete analyses to log resolution for modeling

- Traditional tools and workflows have struggled to fully capture, upscale, and model unconventional heterogeneity

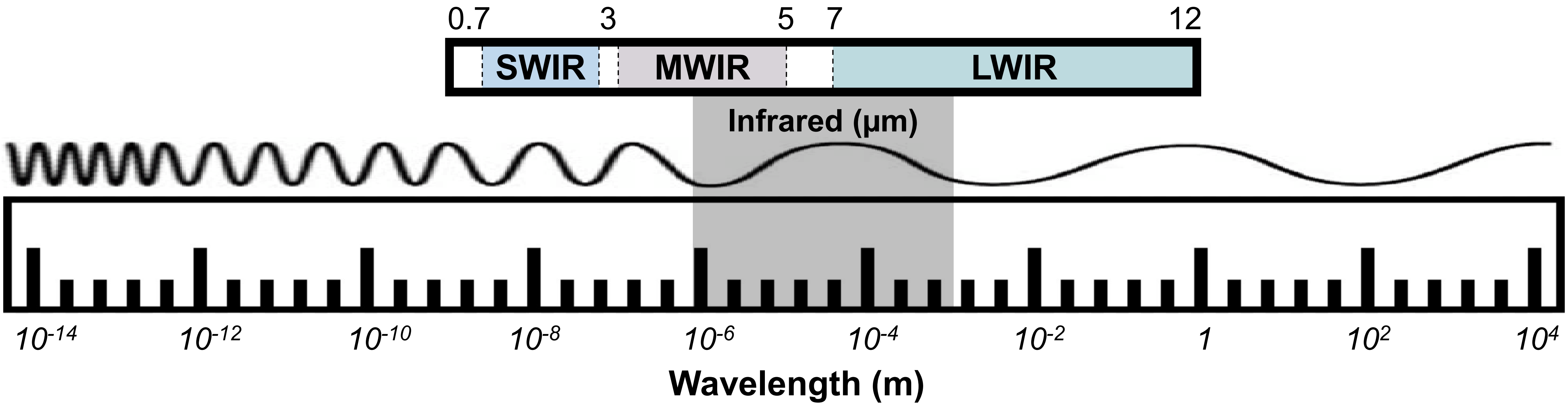
- How can the industry leverage technological advances and big data analytics to more efficiently explore and develop oil and gas resources?

OBJECTIVES

- Capture fine-scale heterogeneities utilizing hyperspectral core imaging from a variety of conventional and unconventional cores
- Provide continuous, quantitative mineralogy by leveraging existing XRD data to develop a new method to calibrate acquired hyperspectral data
- Evaluate calibrated data and results:
  - How accurate is the calibration?
  - What unique value can the calibrated results provide compared to existing analyses?
  - Can the calibrated results be easily integrated into geologic workflows?

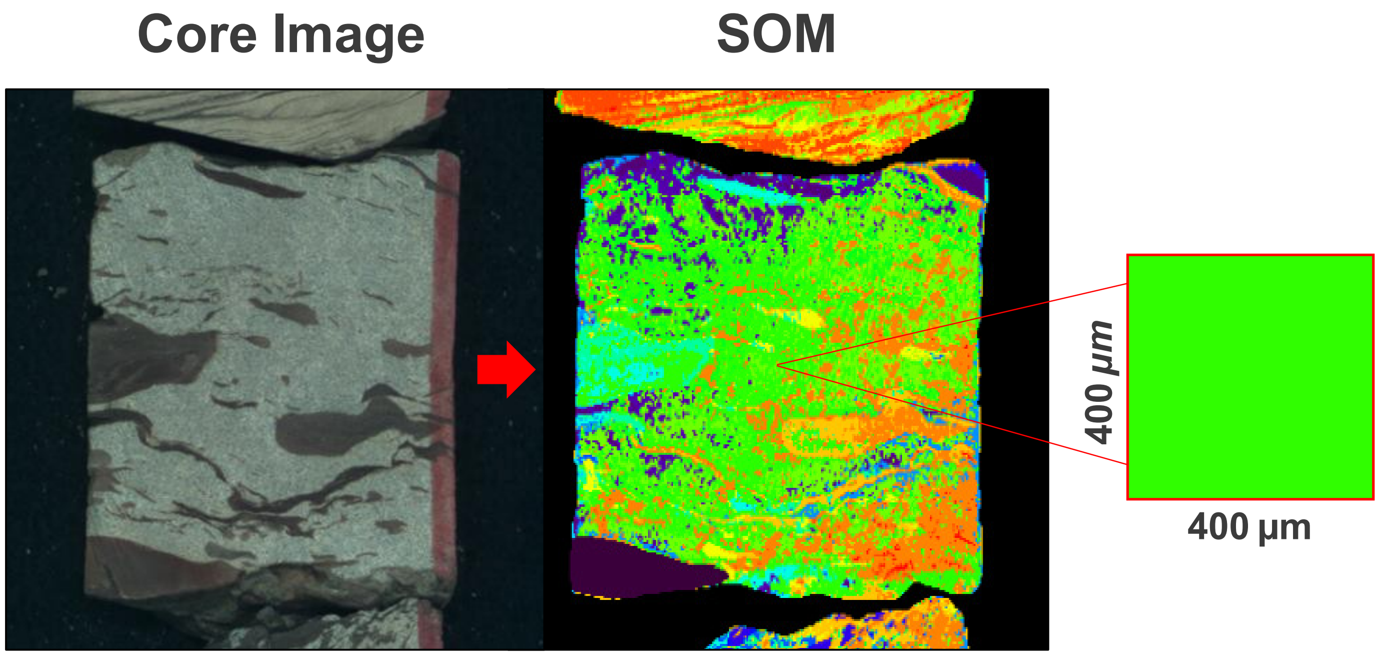
HYPERSPECTRAL CORE IMAGING

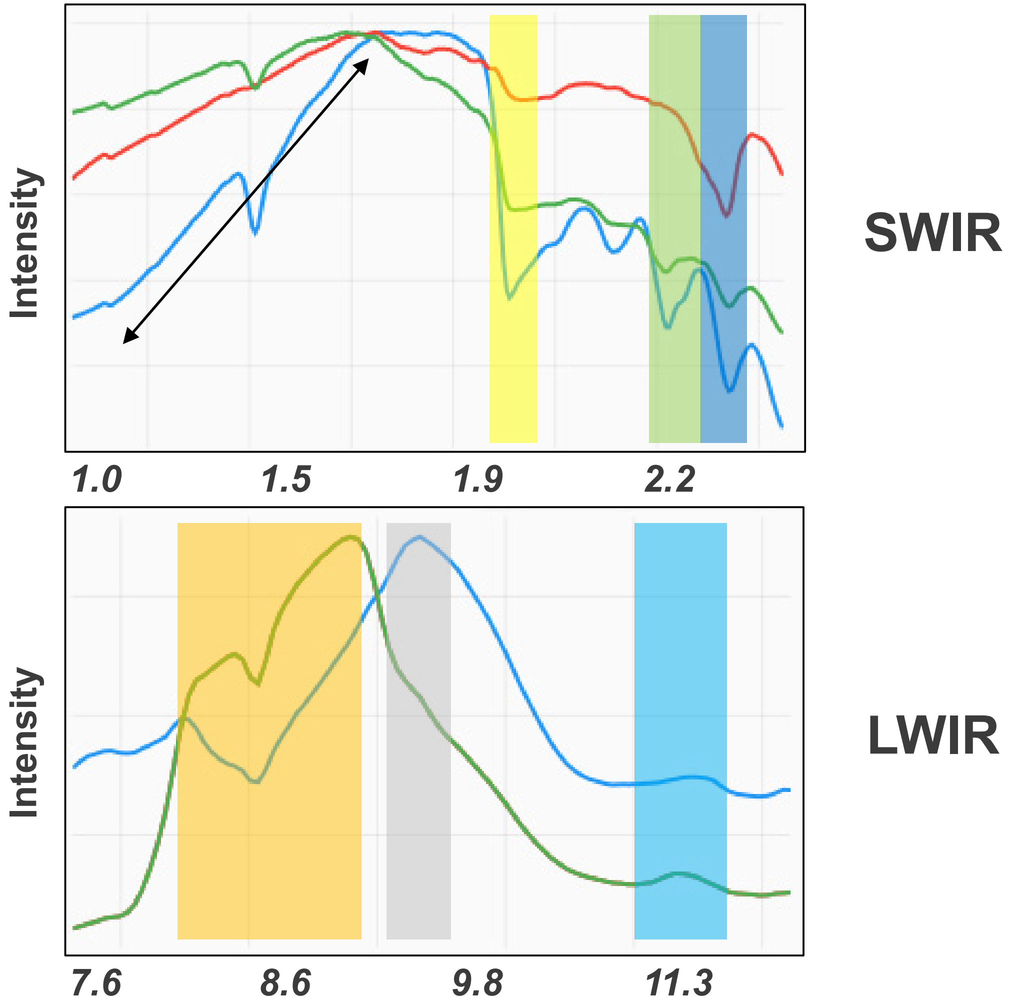
- Hyperspectral imaging is a blend of digital imaging and infrared spectroscopy
- Formation evaluation applications allow mineralogical and textural information to be captured from a variety of sample types including slabbed core, cuttings, and sidewall core faces
- Chemical bonds within minerals produce specific absorption features when excited by energy sources (light or heat) – the resulting combination of absorption features is indicative of mineral or multi-mineral presence



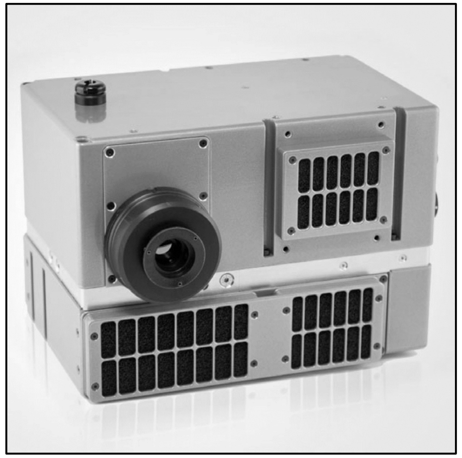
HYPERSPECTRAL CORE IMAGING (CONT.)

- The sensitivity to subtle elemental variations provides an enormous amount of information – a perfect fit for data mining approaches





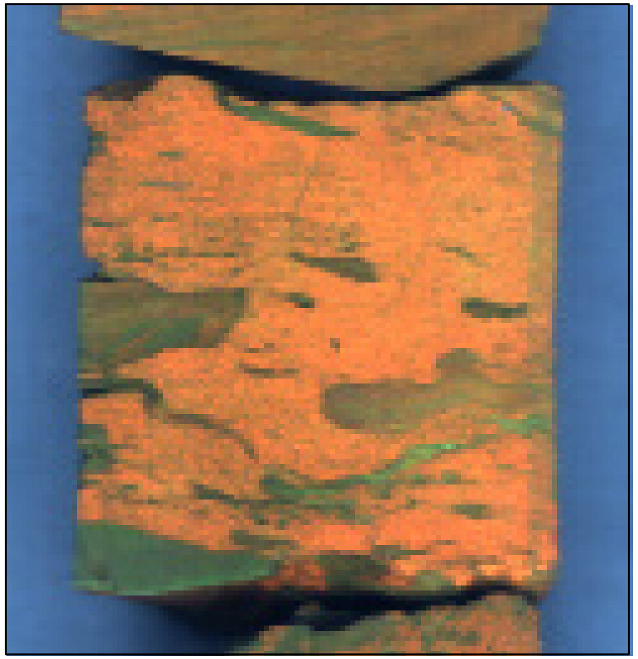
WORKFLOW: DATA ACQUISITION



	SWIR Spectrometer	LWIR Spectrometer
Spectral Range	1000-2500 nm	8000-12000 nm
Spectral Bands	288	84
Spectral Sampling	5.6 nm/band	48 nm/band
Spectral Resolution	12 nm	100 nm
Spatial Resolution	300-500 µm	

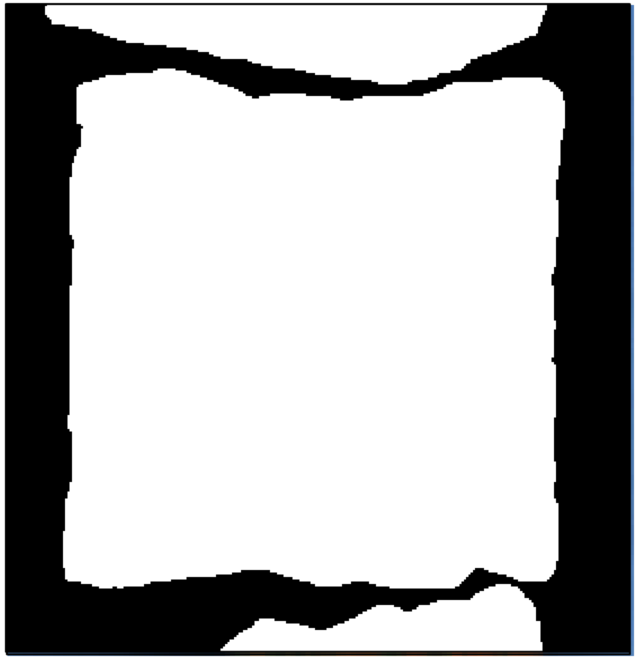
WORKFLOW: DATA PROCESSING

- False color composite image to visualize raw data



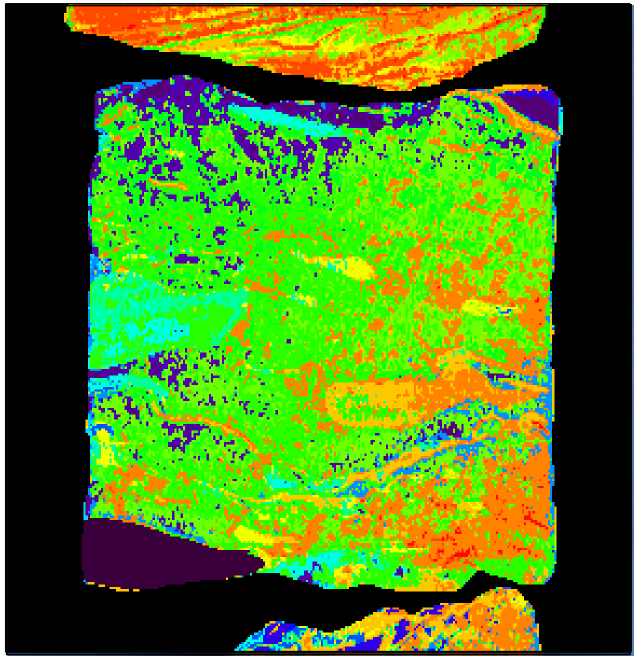
WORKFLOW: DATA PROCESSING

- False color composite image to visualize raw data
- Core masking process to remove background and noise attributing signal



WORKFLOW: DATA PROCESSING

- False color composite image to visualize raw data
- Core masking process to remove background and noise attributing signal
- Artificial neural network (SOM) classification to group spectral and spatial dissimilarities



WORKFLOW: DATA PROCESSING

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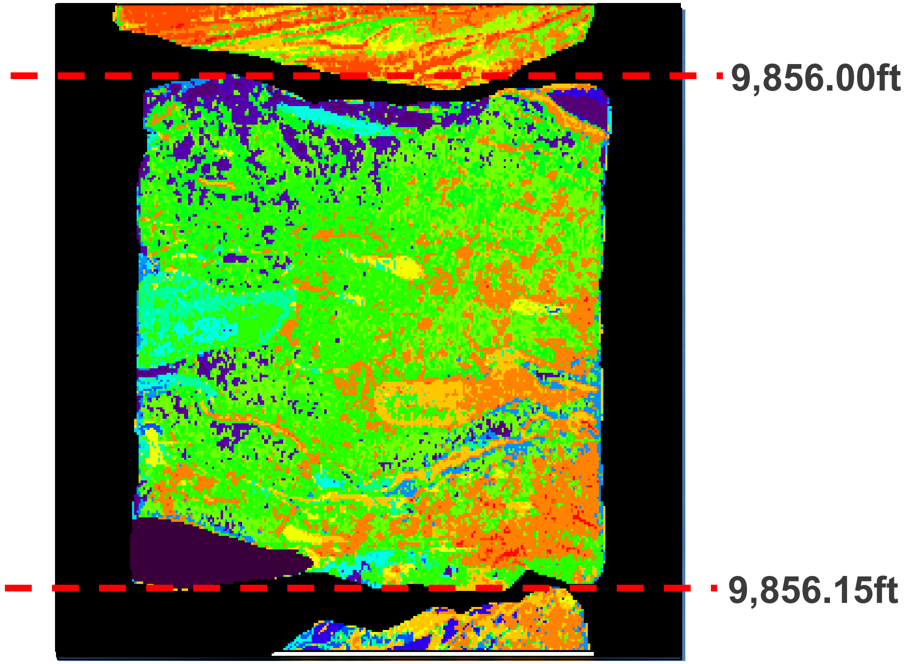
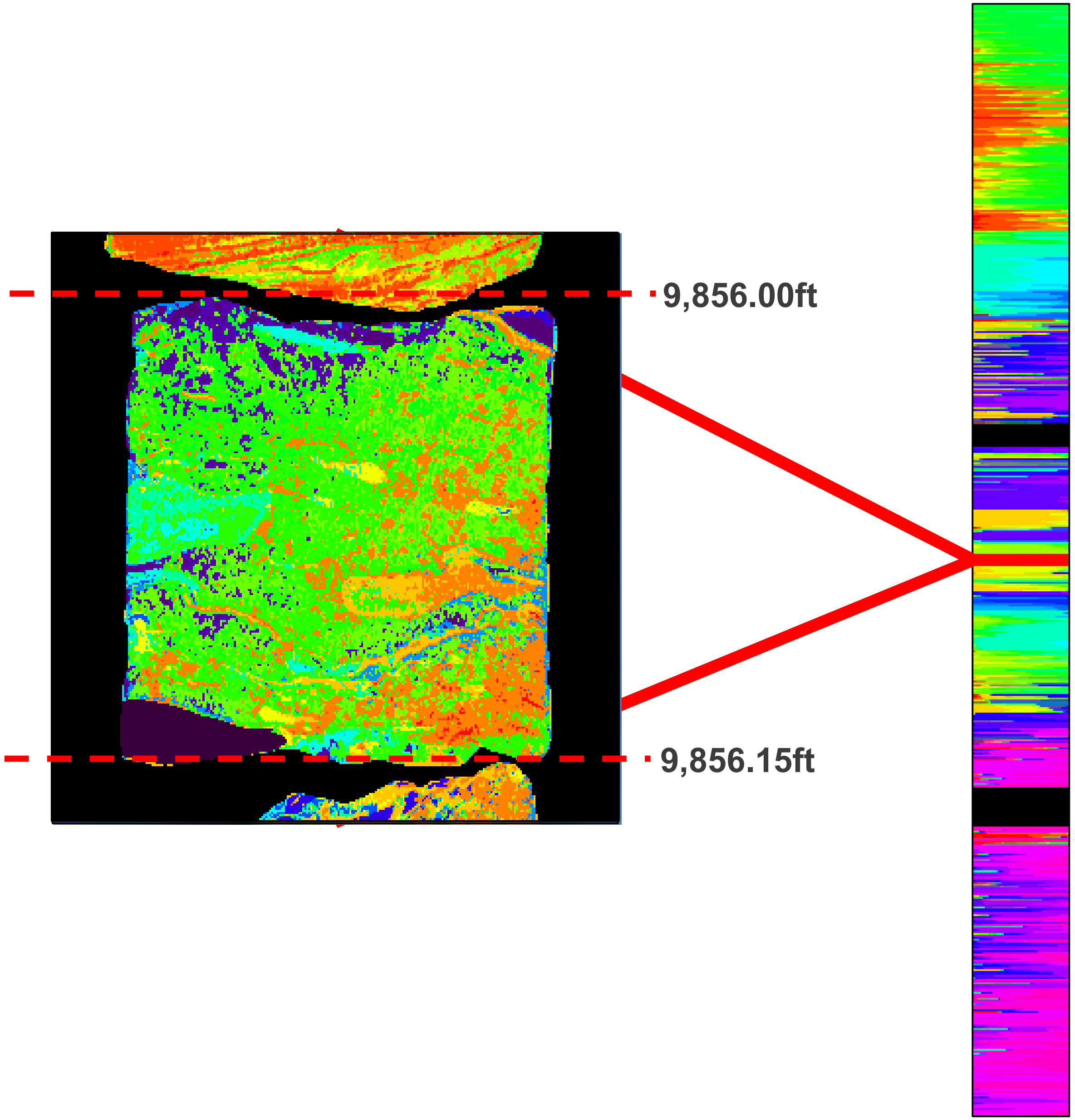
- Image data associated to depth values



WORKFLOW: DATA PROCESSING

- False color composite image to visualize raw data
- Core masking process to remove background and noise attributing signal
- Artificial neural network (SOM) classification to group spectral and spatial dissimilarities
- Image data associated to depth values
- SOM image data generated into empirical log format

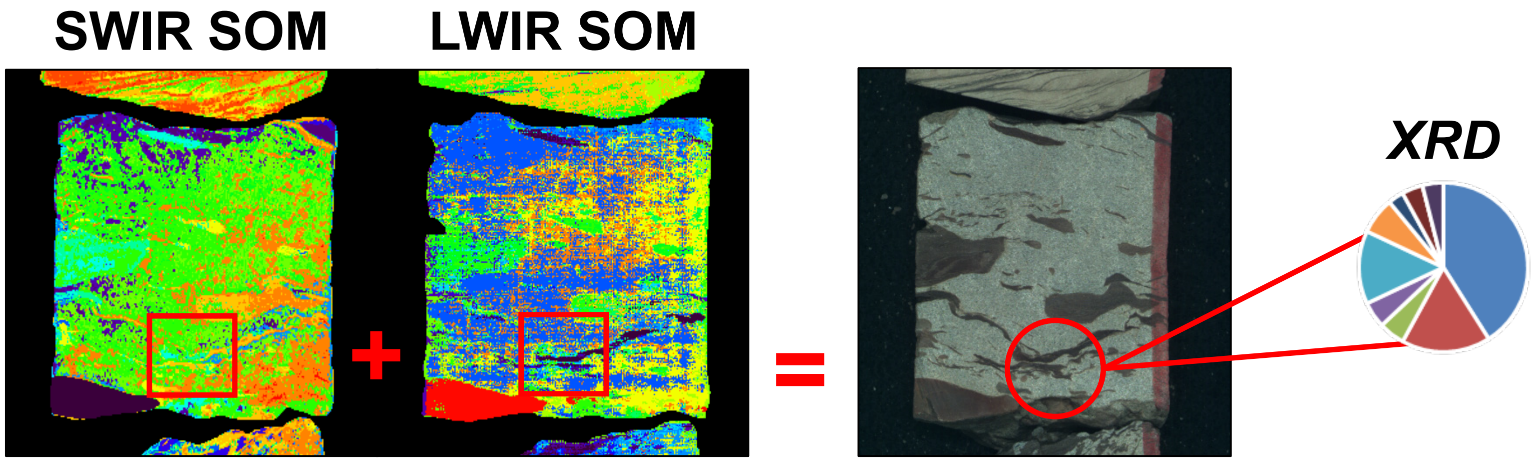


WORKFLOW: MODEL BUILDING

- Lookup query is used to associate the combined series of SWIR + LWIR SOM data with each XRD control point

- SOM-XRD associations are compiled to build a multi-dimensional system of equations

$$\begin{bmatrix} x_{1,1} & x_{2,1} & \cdots \\ x_{1,2} & x_{2,2} & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix} \quad \begin{bmatrix} z_{1,1} & z_{2,1} & \cdots \\ z_{1,2} & z_{2,2} & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix} \qquad \begin{bmatrix} y_1 \\ y_2 \\ \vdots \end{bmatrix}$$



WORKFLOW: MODEL BUILDING (CONT.)

- Constraints are implemented:
  - Prevent sum of abundances greater than unity (100%)
  - Prevent sum of individual mineral species greater than mineral group

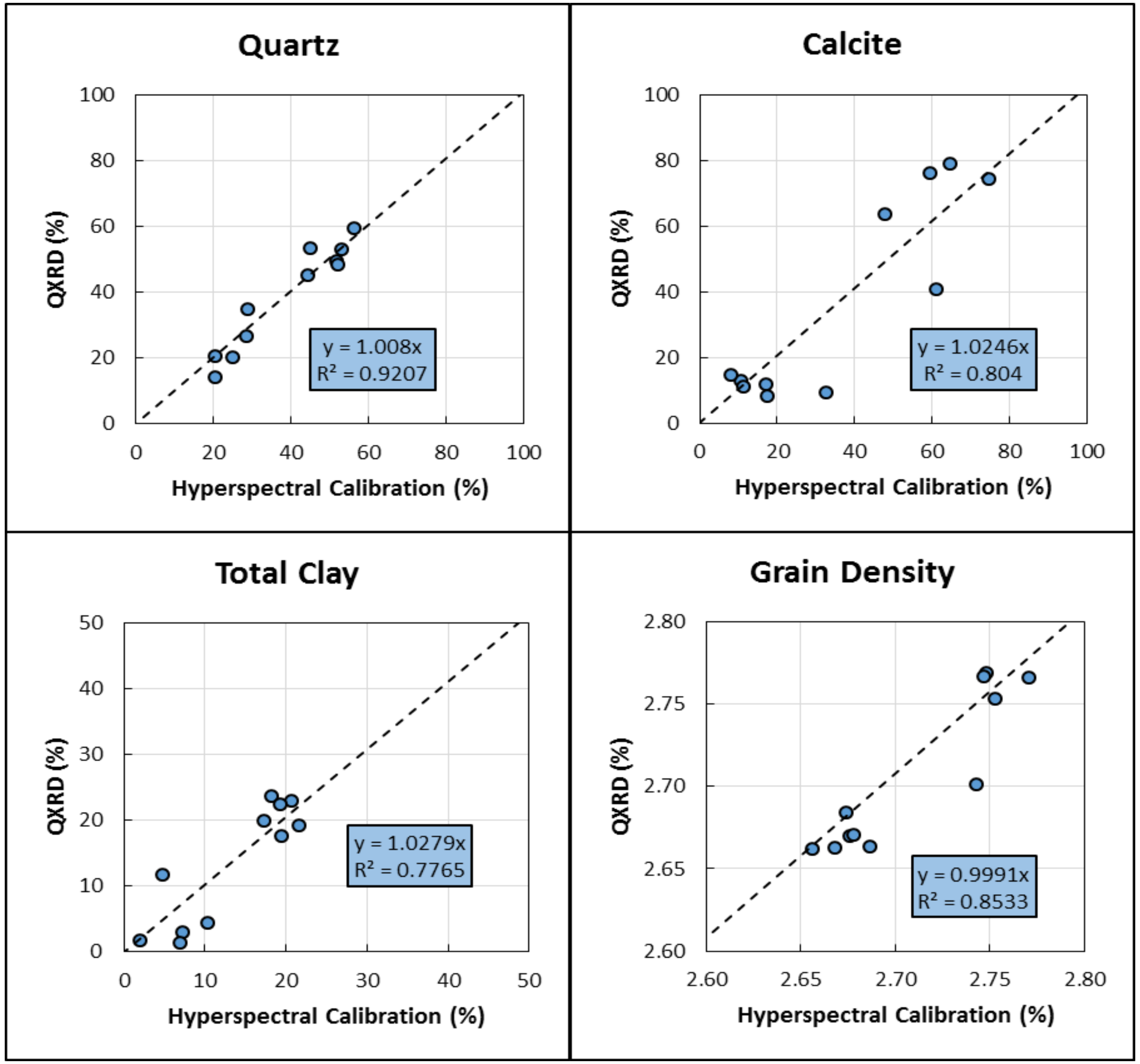
Tectosilicates	Quartz, Plagioclase, K-Feldspar
Carbonates	Calcite, Dolomite
Phyllosilicates	Illite & Mica, Illite-Smectite, Kaolinite, Chlorite

- Hierarchal series of regressions are performed by residual sum of squares and/or root mean square error conditions

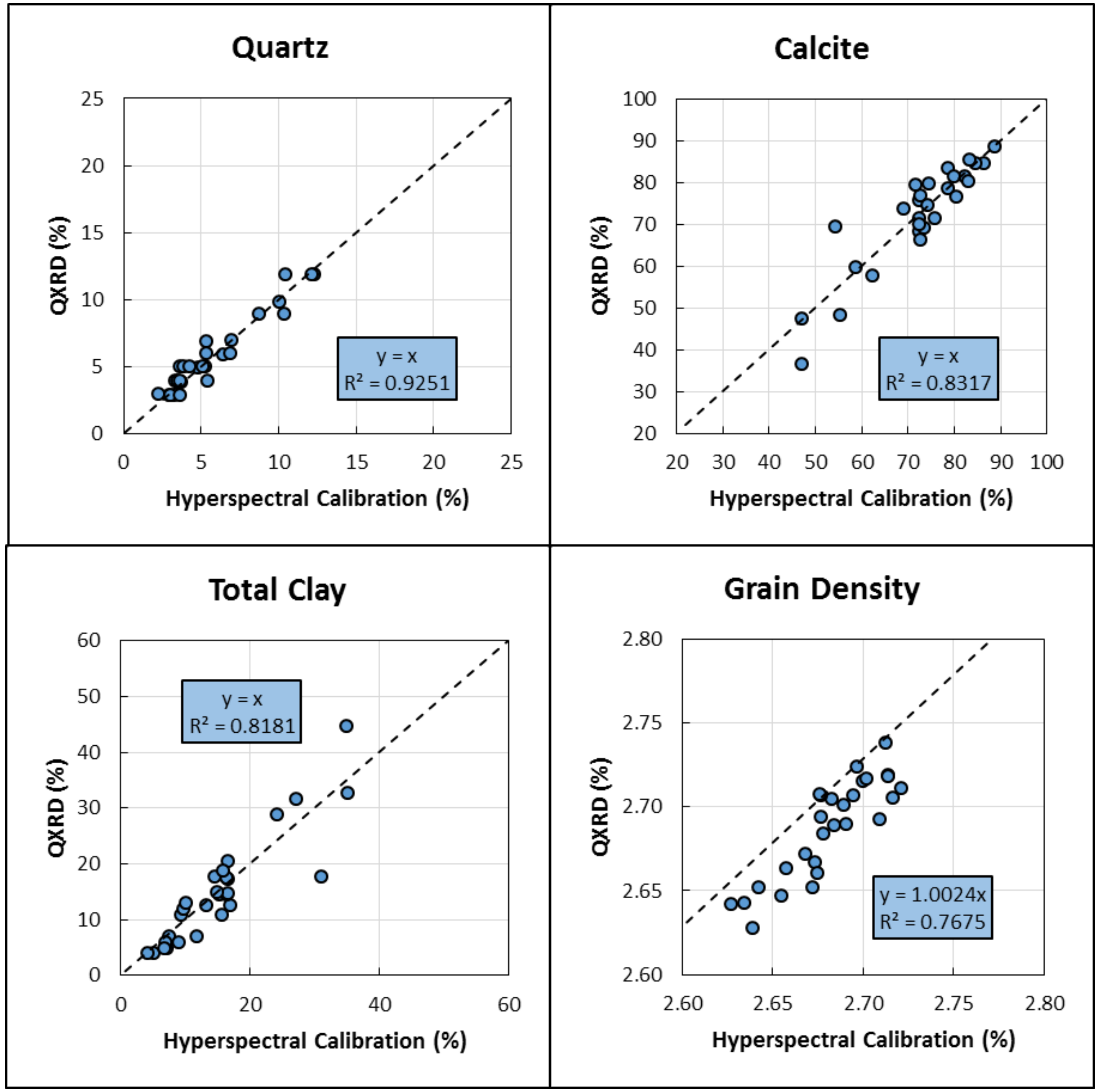
- Solved variables then applied to excluded XRD control points for forward modeling validation

CALIBRATION RESULTS

Third Bone Spring (N=11)

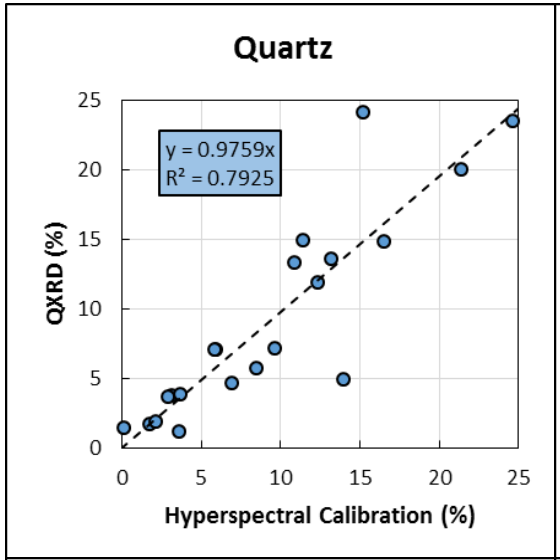


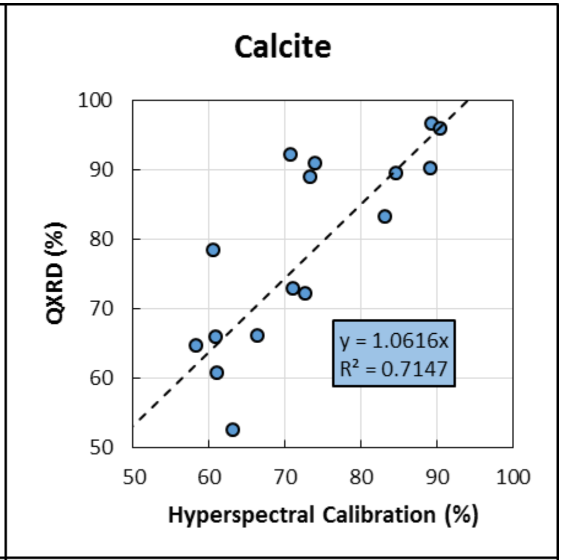
Austin Chalk (N=28)

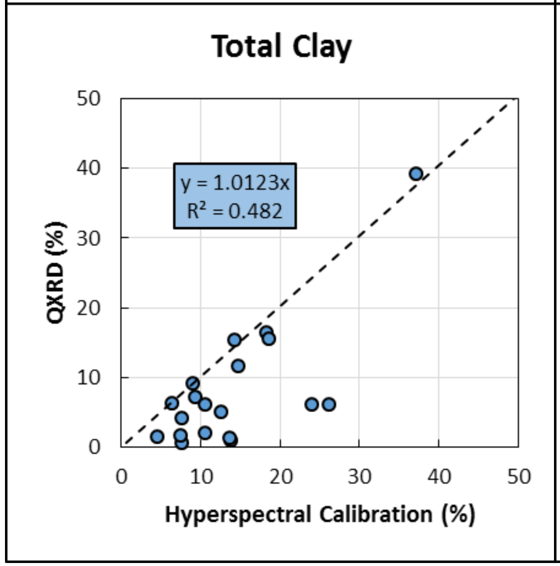


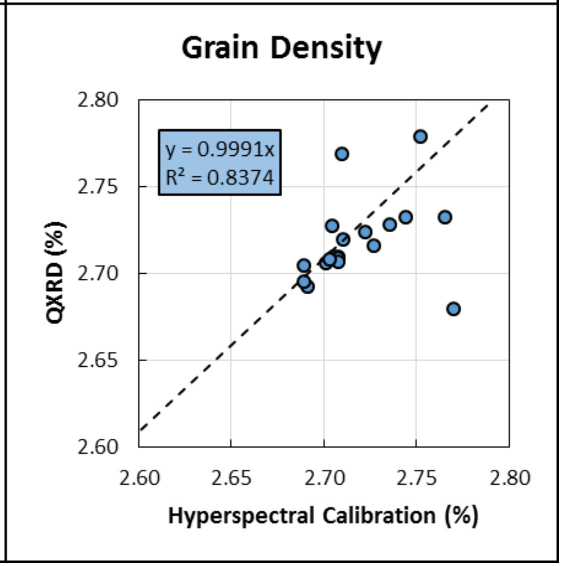
CALIBRATION RESULTS (CONT.)

Eagle Ford (N=21)

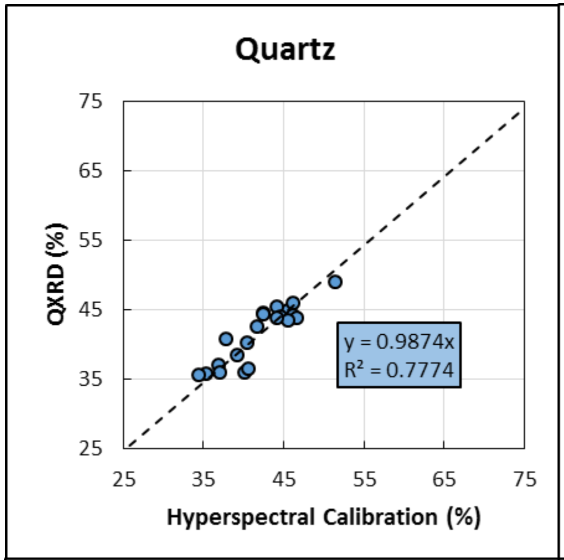


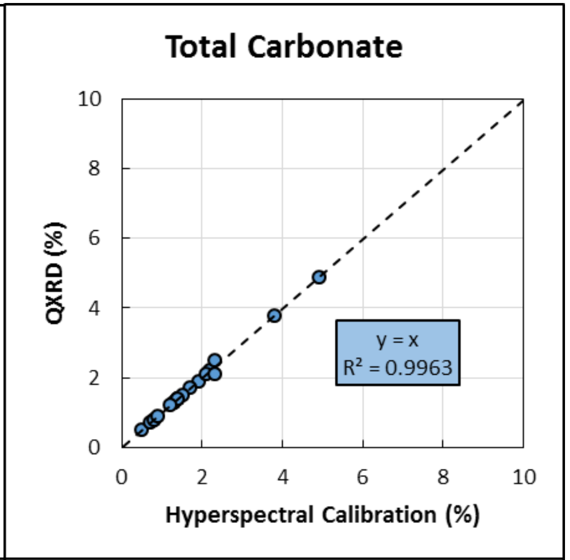


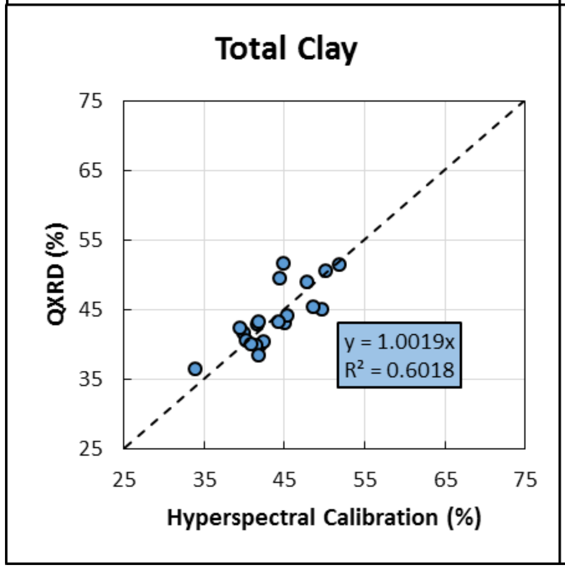


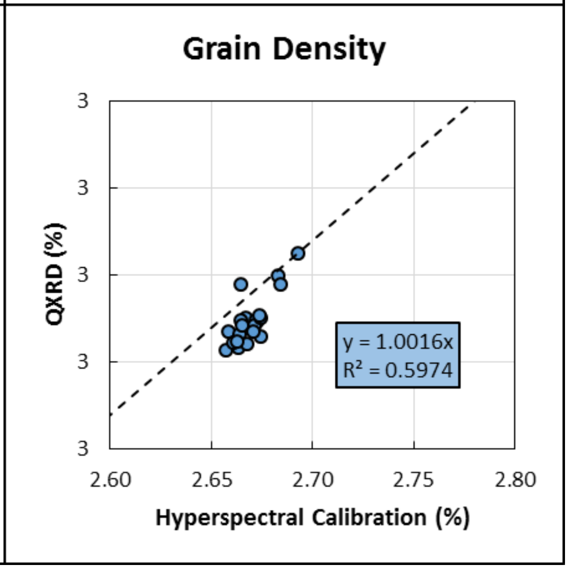


Wilcox (N=21)





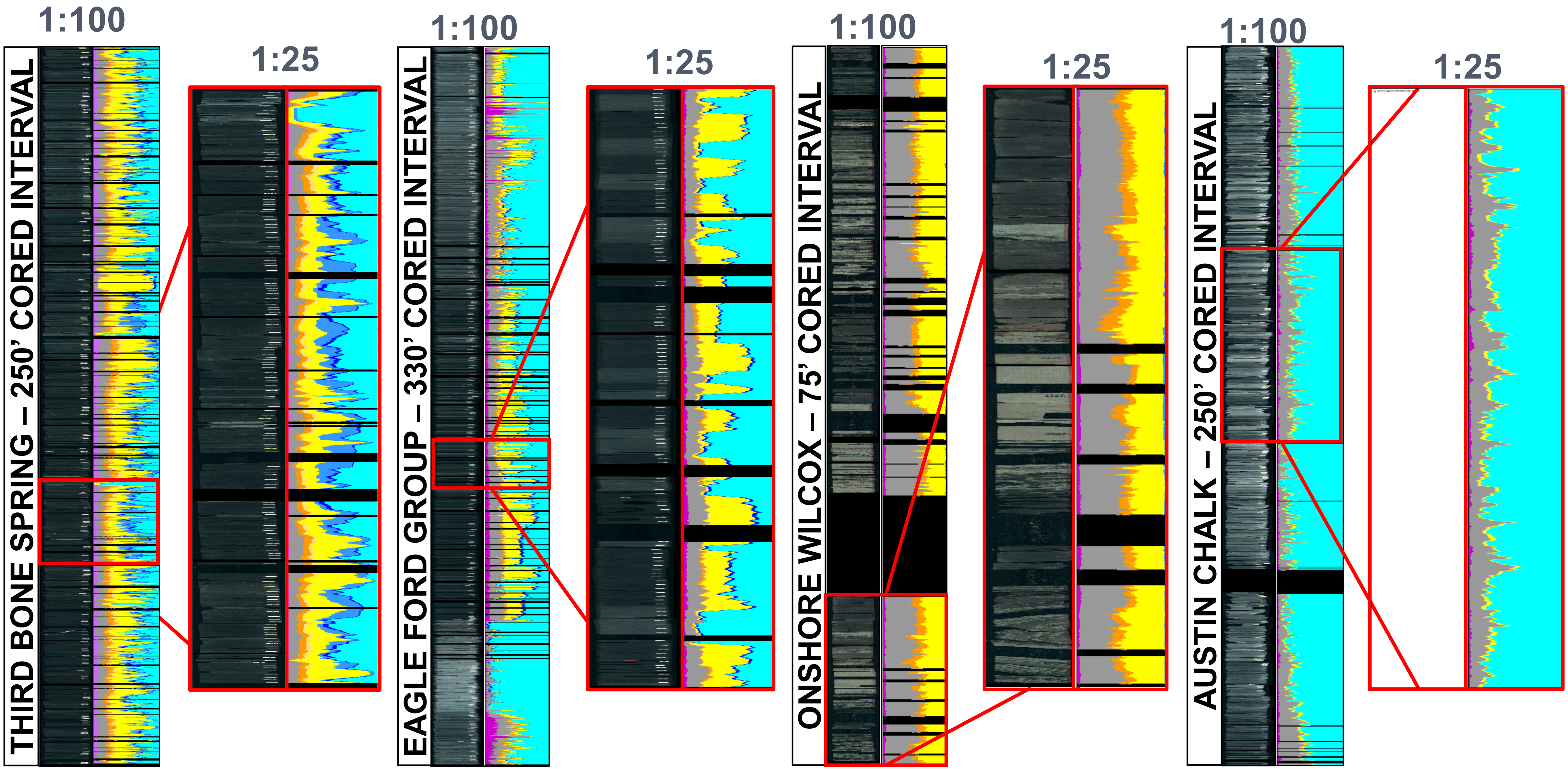




CALIBRATION ASSUMPTIONS

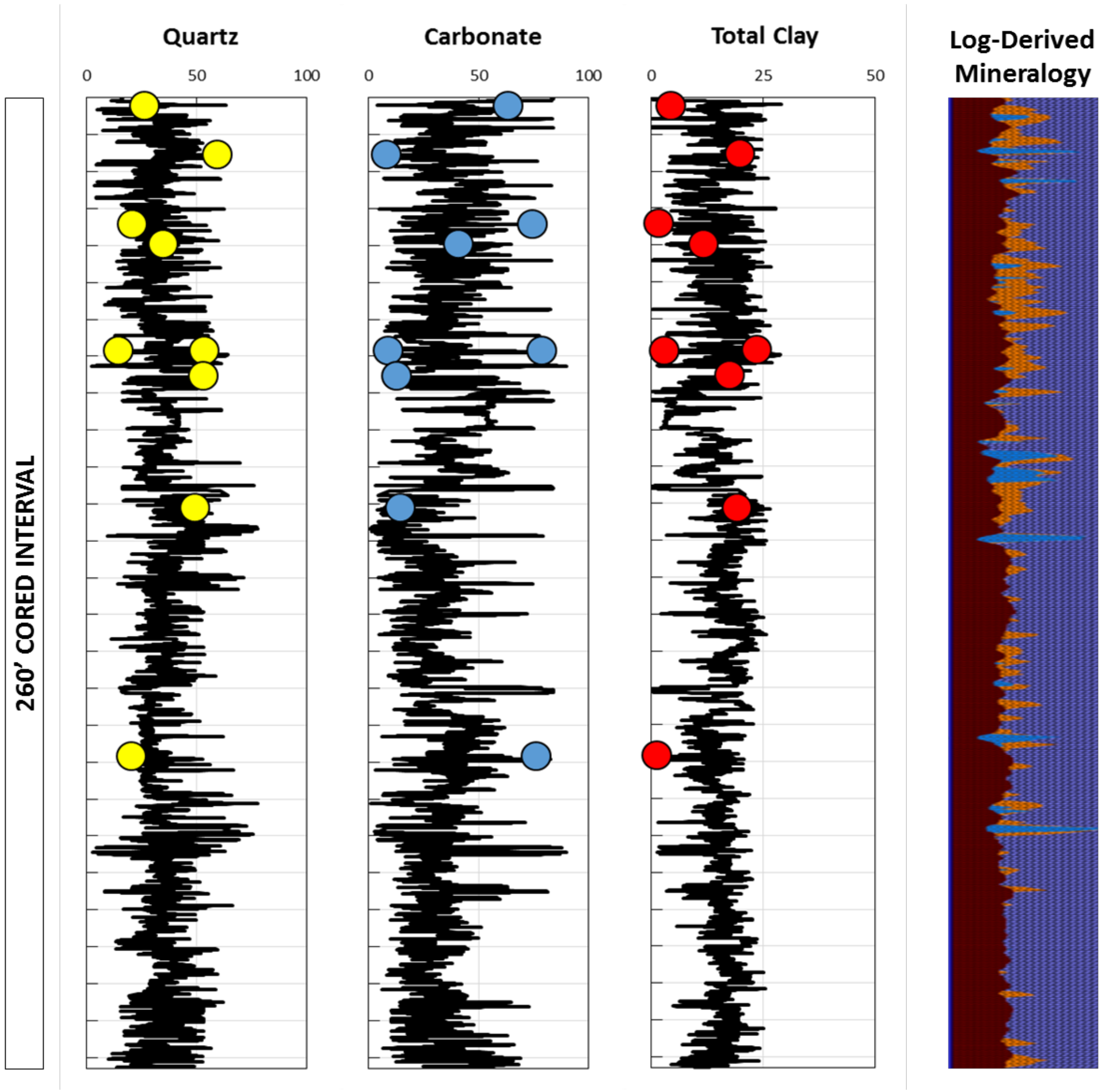
- All variations in composition and texture are encompassed in the SOM classifications
- By calibrating to an external dataset, the model assumes the validity and accuracy of that dataset
- Predictive capability of the calibrated results is a direct function of the number of calibration points, as well as the range of SOM classifications they cover
- Bulk hyperspectral data and the associated external dataset point involve the same representative rock area/volume
- Differences between the comparative area/volume can contribute to less accurate calibrations

UPSCALED CORE CALIBRATION



UPSCALED CORE CALIBRATION (CONT.)

- Thin interbedded layers and laminae are captured and quantified
- The addition of high-resolution, continuous mineralogical trends with depth adds significant understanding compared to discrete XRD point analyses



CONCLUSIONS

- Hyperspectral core imaging effectively captures high-resolution mineralogical variations on the slabbed core surface that are not visually identifiable

- Positive relationships between the SOM mineral model and known XRD values indicate the SOM classifications are successfully separating the high/low limits of the XRD values

- The R^2 values close to 1 indicate the calibration mathematics are predicting the mineral abundances with minimal scatter

- Quantitative, continuous mineralogy offers improved characterization of lithological units:
  - Net-to-gross determinations and landing zone refinement
  - Predicting geomechanical impacts for completion design

- Opportunities for future development and evaluation:
  - Artificial intelligence applications – can calibrations become more universal?
  - MWIR sensitivity to hydrocarbons – is organic characterization possible?

THANK YOU