PSWhere Are the Hydrocarbons? Silicilastic versus Carbonate Micropores in the Middle Member of the Bakken Formation*

T. Kosanke[1], S. Egenhoff[2], J. Greene[1], X. Liu[1], B. Porter[1], and N. Fishman[3]

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[1]ALS Oil & Gas, Houston, TX, United States (Tobi.Kosanke@ALSGlobal.com)
[2]Colorado State University, Fort Collins, CO, United States
[3]PetroLogic Solutions, LLC, Boulder, CO, United States

Abstract

The middle Bakken member in the Williston Basin of North Dakota represents a mixed carbonate-siliciclastic unit consisting of predominantly siltstones. This oil-rich interval is sandwiched between two black shales, the upper and lower Bakken, both considered source rocks for the middle member. Previous petrographic studies of the middle Bakken have identified a variety of pore types, with intercrystalline and dissolution porosity being ascribed to the process of dolomitization, largely due to the observation that in thin sections, large pores are associated with the presence of dolomite. In this study, we combine thin section petrography, SEM imaging of Ar-ion milled samples, and hyperspectral core imaging to characterize the types of porosity in the middle Bakken and identify the location of oil-containing pores. We found that the observation of visible porosity being contained within the dolomite-rich laminations is likely an artifact of thin section sample preparation. SEM imaging our samples indicates that porosity was not produced by of dolomitization, but rather preserved within the clay-rich laminations. The oil is contained in pores of these clay-rich laminations, residing in the spaces between clay lathes and around dolomite rhombs that they abut. The pores in the carbonate-rich laminations, originally thought to be filled with oil, are occluded by multiple phases of calcite, dolomite and ferroan dolomite cement, all of them degrading reservoir quality. Hyperspectral imaging of middle Bakken core enabled us to produce mineral and hydrocarbon maps of the middle Bakken, which clearly show that the presence of hydrocarbons is limited to the clay-rich laminations. While previous studies have attempted to show that porosity in the middle Bakken is associated with dolomitization, we can illustrate that the oil-containing pores are limited to the clay-rich laminations and that cementation in the carbonate-rich laminations occludes, rather than preserves or creates, porosity.

Reference Cited

Kurtoglu, B., 2013, Integrated reservoir characterization and modeling in support of enhanced oil recovery for Bakken: Ph.D. Dissertation, Colorado School of Mines, 239 p., Web Accessed July 4, 2018, https://dspace.library.colostate.edu/bitstream/handle/11124/24/Kurtoglu_mines_0052E_10341.pdf?sequence=1

WHERE ARE THE HYDROCARBONS? SILICILASTIC VERSUS CARBONATE MICROPORES IN THE MIDDLE MEMBER OF THE BAKKEN FORMATION

T. Kosanke[1], S. Egenhoff[2], J. Greene[3], X. Liu[3], B. Porter[3], N. Fishman[4]

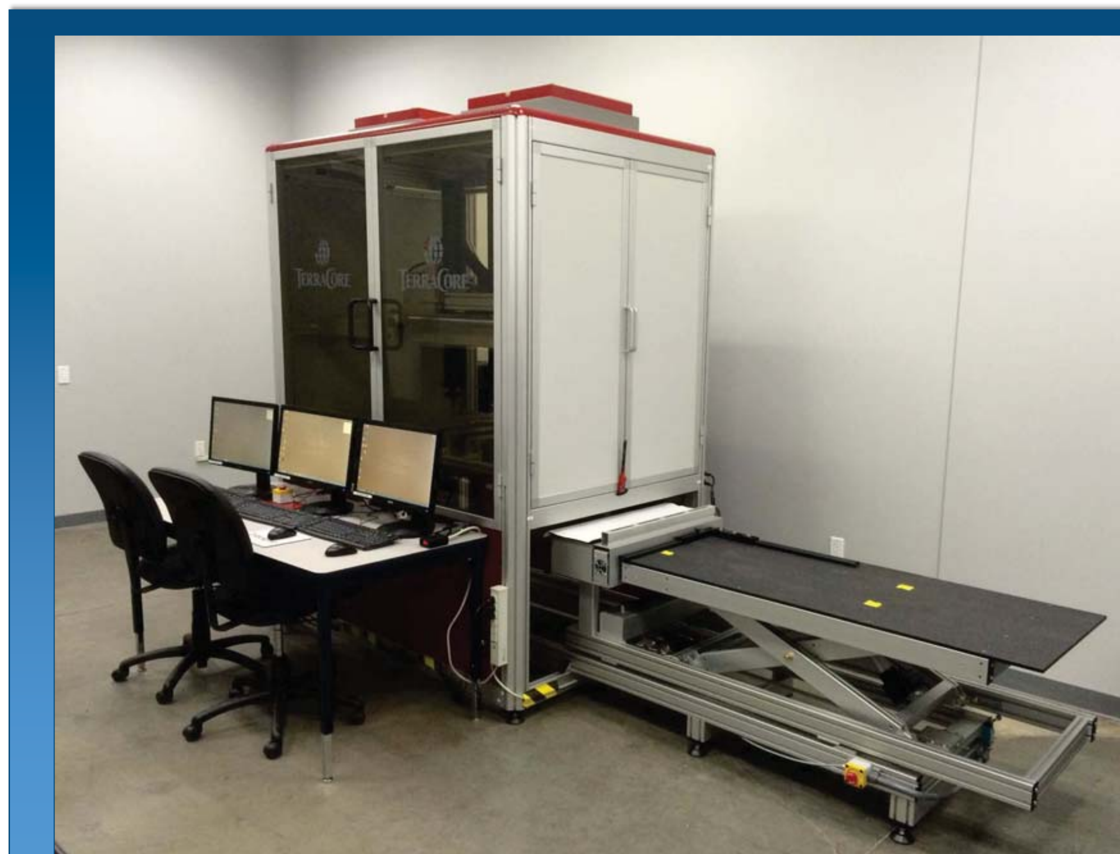
1 - Independent Consultant ALS Oil & Gas Laboratories, Houston, TX; 2 – Colorado State University, Fort Collins, CO; 3 – ALS Oil & Gas Laboratories, Houston, TX; 4 – PetroLogic Solutions LLC, Boulder, CO

Abstract

The middle Bakken member in the Williston Basin of North Dakota represents a mixed carbonate-siliciclastic unit consisting of predominantly siltstones. This oil-rich interval is sandwiched between two black shales, the Upper and Lower Bakken, both considered source rocks for the middle member. Previous petrographic studies of the middle Bakken have identified a variety of pore types, with intercrystalline and dissolution porosity being ascribed to the process of dolomitization, largely due to the observation that in thin sections, large pores are associated with the presence of dolomite.

In this study we combine thin section petrography, SEM imaging of Ar-milled samples, and hyperspectral core imaging to characterize the types of porosity in the middle Bakken and identify the location of oil-containing pores. We found that the observation of visible porosity being contained within the dolomite-rich laminations is likely an artifact of thin section sample preparation. SEM imaging of our samples indicates that porosity was not produced by of dolomitization, but rather preserved within the clay-rich laminations. The oil is contained in pores of these clay-rich laminations, residing in the spaces between clay lathes and around dolomite rhombs that they abut. The pores in the carbonate-rich laminations, originally thought to be filled with oil, are occluded by multiple phases of calcite, dolomite and ferroan dolomite cement, all of them degrading reservoir quality.

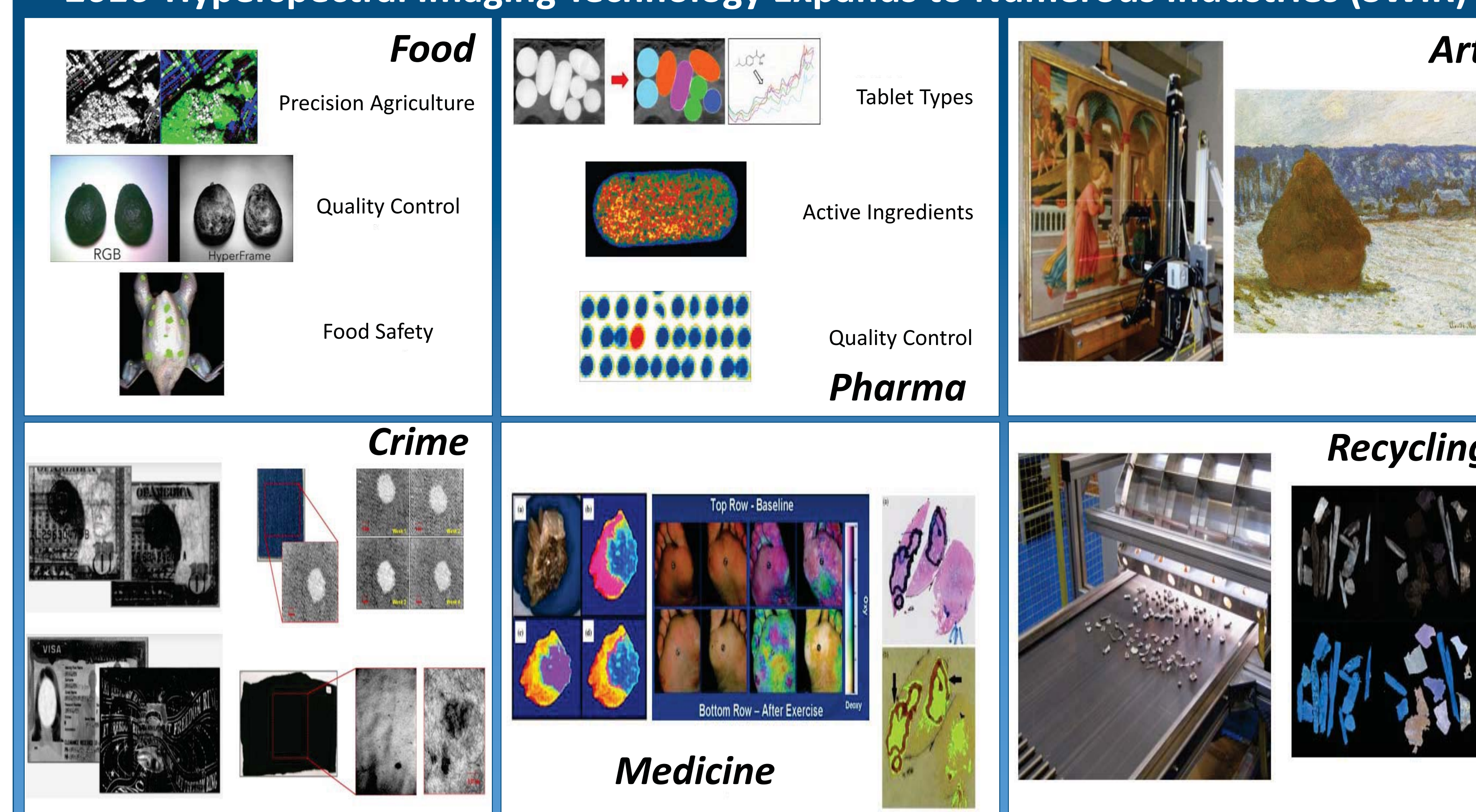
Hyperspectral imaging of Middle Bakken core enabled us to produce mineral and hydrocarbon maps of the middle Bakken, which clearly show that the presence of hydrocarbons is limited to the clay-rich laminations. While previous studies have attempted to show that porosity in the middle Bakken is associated with dolomitization, we can illustrate that the oil-containing pores are limited to the clay-rich laminations that contain growing (not dissolving) dolomite rhombs and that cementation in the calcite-rich laminations occludes, rather than preserves or creates, porosity.



Top: Acquisition of infrared spectral data via high-wattage LED light reflectance.

Left: Hyperspectral Imaging System at ALS Oil & Gas Laboratory in Houston, TX. Three spectrometers in succession (RGB, SWIR, LWIR) were used to acquire spectral data on the middle Bakken interval.

2010-Hyperspectral Imaging Technology Expands to Numerous Industries (SWIR)



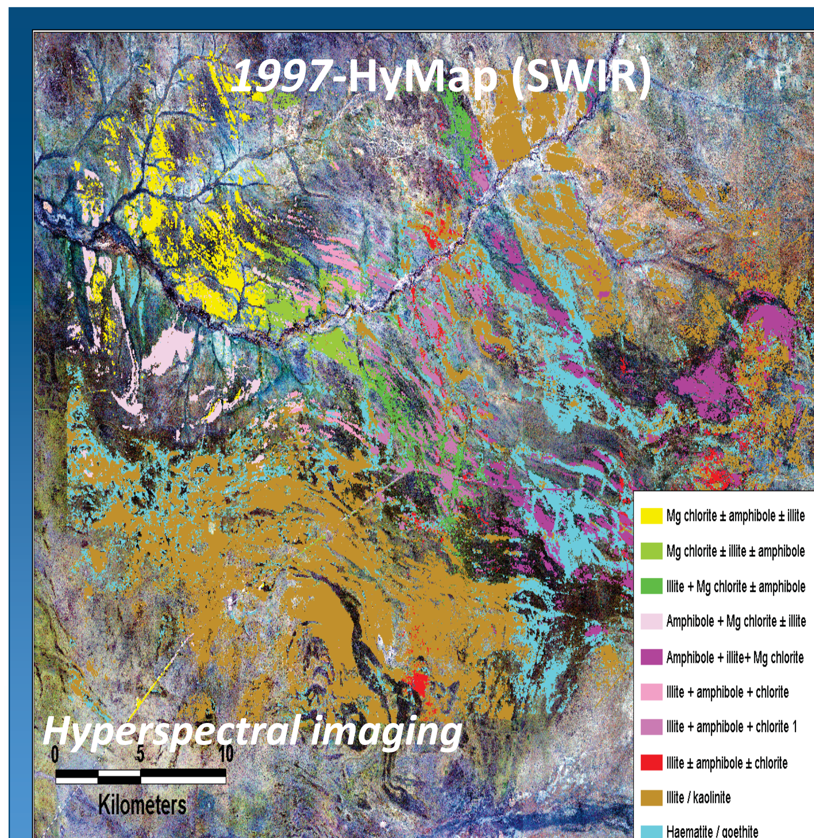
1970-Multispectral Imaging

First earth observation satellite, Landsat, using multi-spectral sensors (60-90m pixels)

First airborne hyperspectral systems developed. Daedalus, operated by Texaco, were early adapters, but effectiveness was limited.

AVIRIS airborne hyperspectral instrument owned and operated by NASA for research. HyMap instruments appear as one of first commercial airborne systems, followed by SpecIm and Norsk Elektro Optik.

1997-HyMap (SWIR)

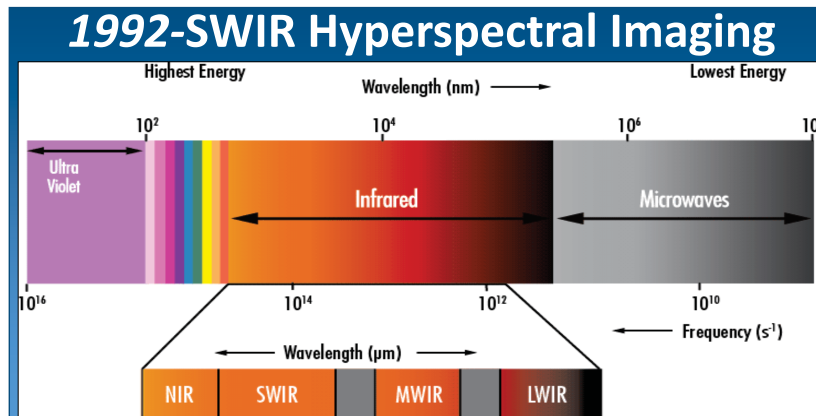


First sisuROCK instruments and introduction of shortwave (SWIR) hyperspectral imaging of core; ***can't detect tectosilicates.***

1970s | Early 1980s | Late 1980s | 1991 | 1992 | Late 1990s | 2003 | 2004 | 2007 | 2013 | 2016

Upgraded Landsat satellite systems with better spatial and spectral resolution (10-30m)

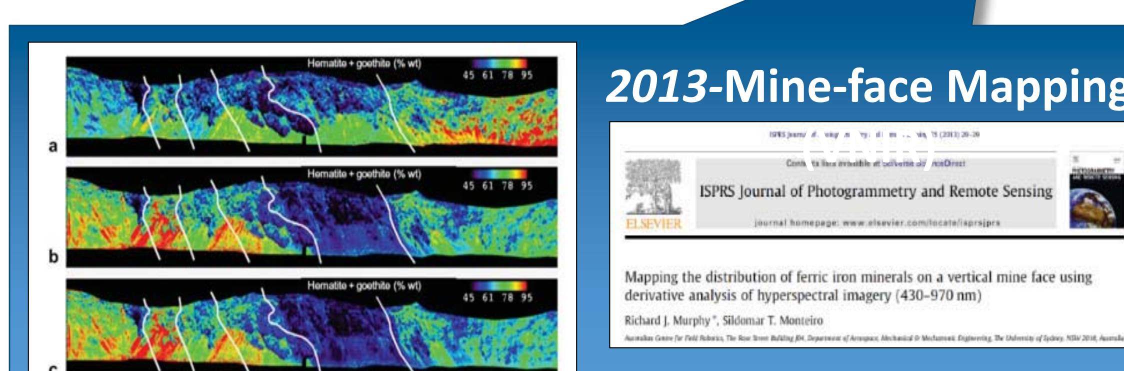
1992-SWIR Hyperspectral Imaging



High spatial resolution satellites (Quickbird and Ikonos)

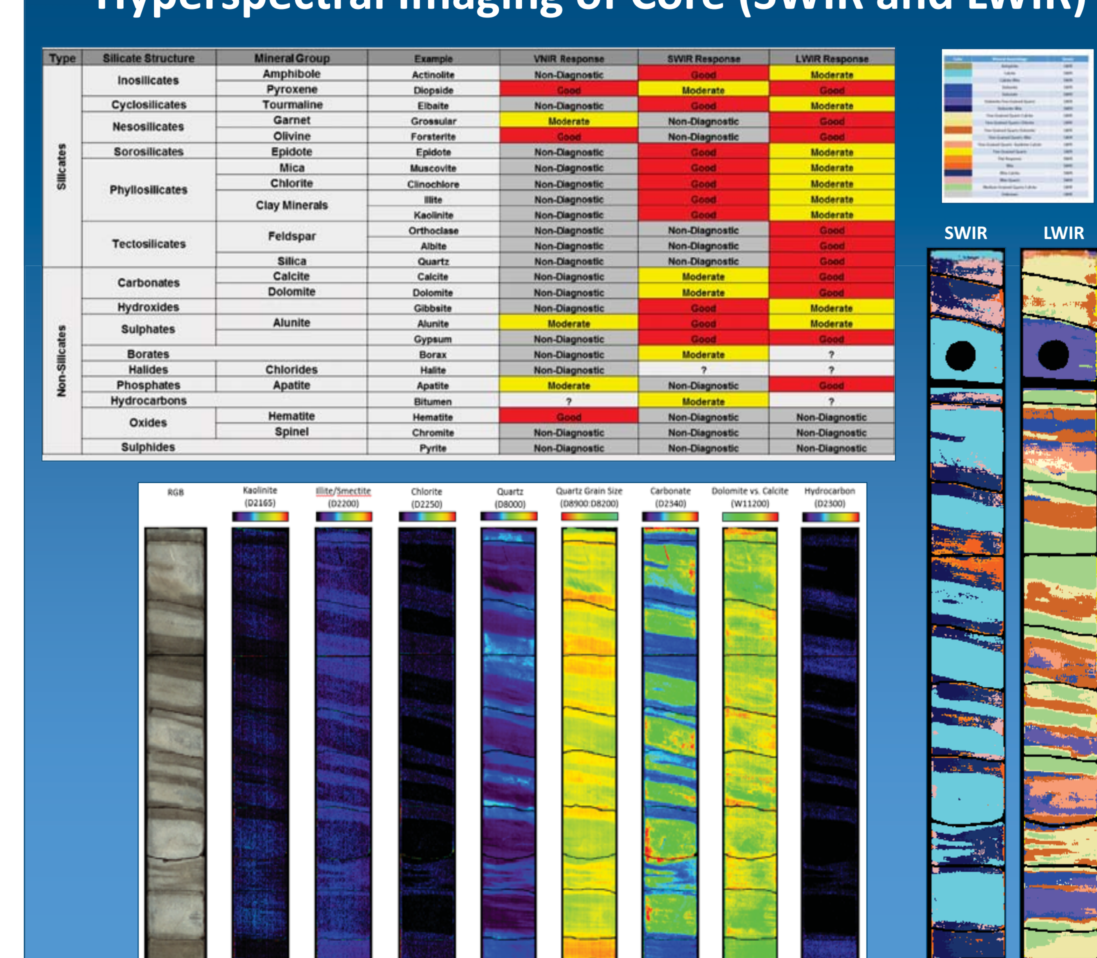
ASTER appears, the culmination of the coarse spatial resolution multispectral satellites.

2013-Mine-face Mapping



Introduction of high-resolution shortwave (SWIR) and longwave (LWIR) hyperspectral imaging of core

2017-ALS Oil and Gas/Terracore High-Resolution Hyperspectral Imaging of Core (SWIR and LWIR)



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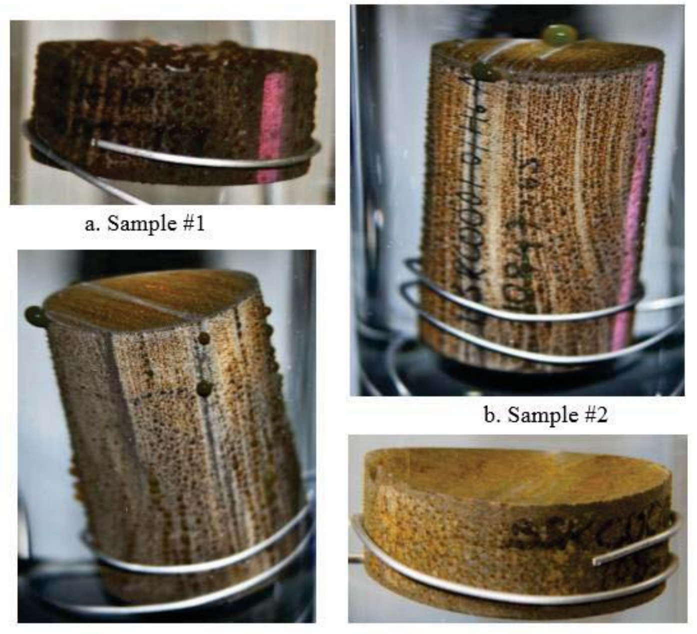
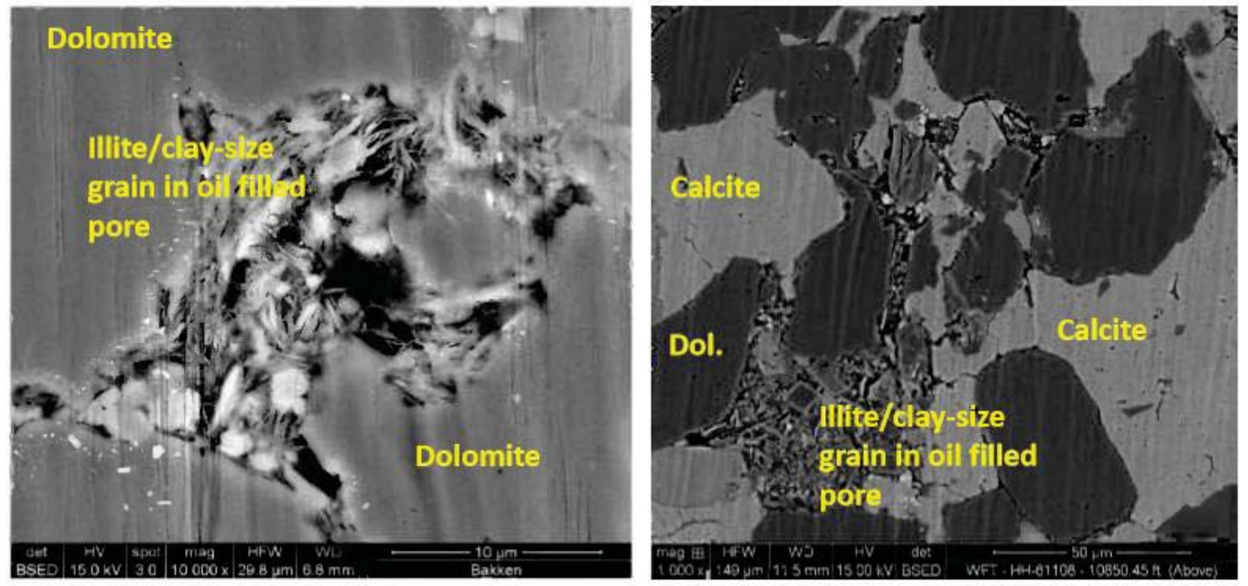


a. Sample #1 b. Sample #2 c. Sample #3 d. Sample #4

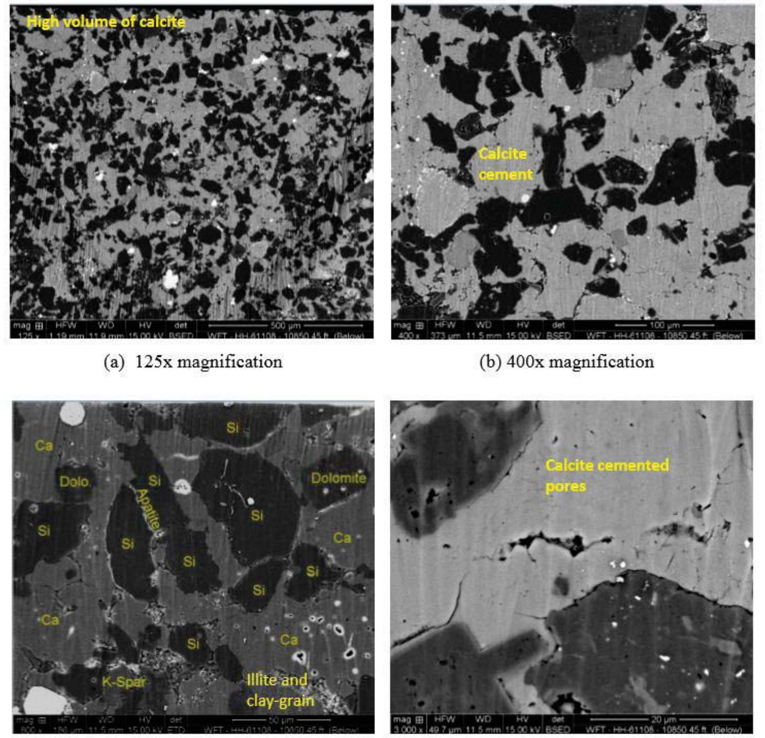
Left: Middle Bakken core plugs immersed in brine, showing blebs of oil escaping along the brown, clay-filled laminae *(Kurtoglu, 2013).*

Right and Below: Argon ion-milled back scattered SEM images of core plugs shown to the left *(Kurtoglu, 2013).* The pores in the clay-rich laminae are filled with oil. There is no evidence of porosity having been created by conversion of calcite to dolomite. Note that the dolomite rhombs are growing within the clay-rich laminations, pushing the clay aside, as opposed to dissolving to create porosity.



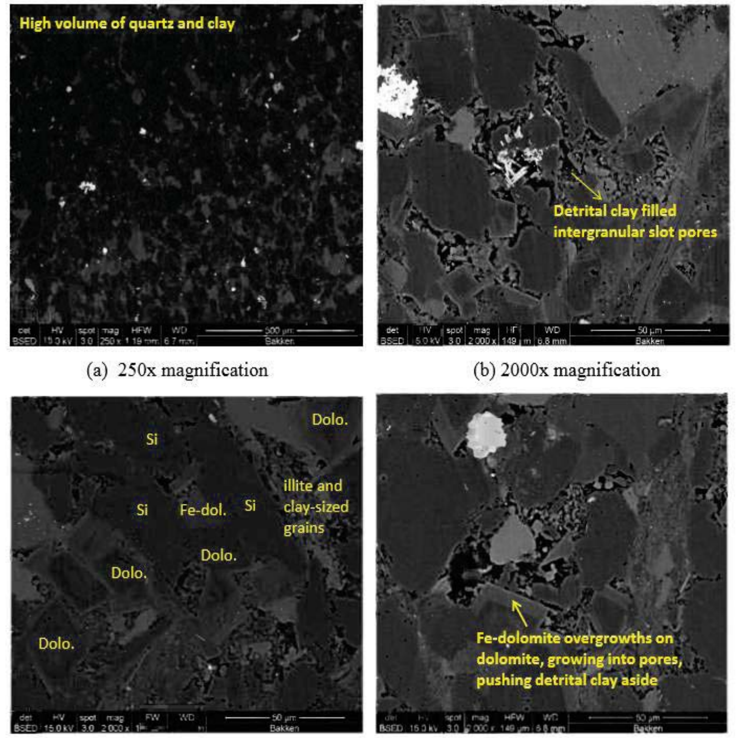
a. Sample #1- 10000x magnification b. Sample #4 - 1000x magnification

Low Permeability Sample



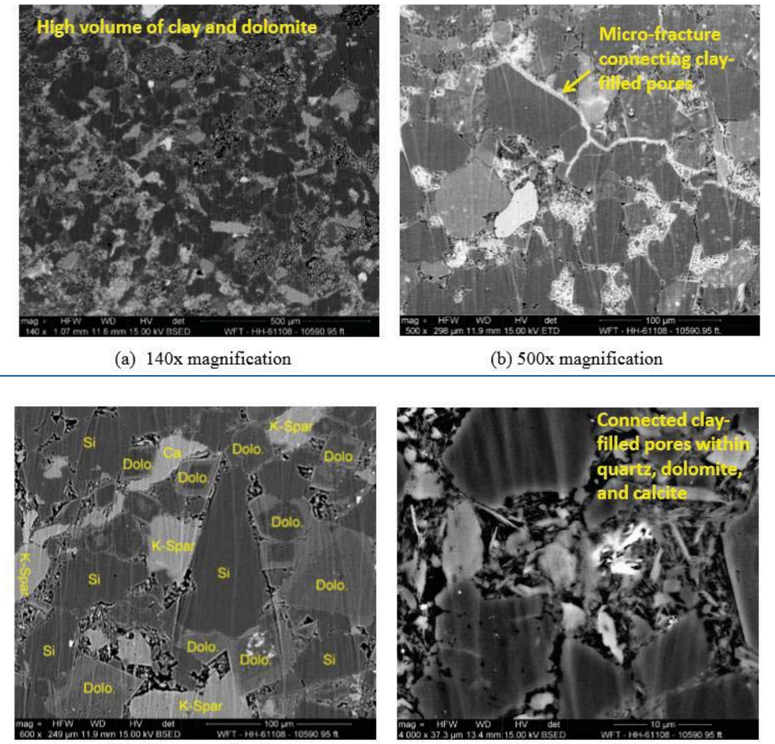
(a) 125x magnification (b) 400x magnification (c) 800x magnification (d) 3000x magnification

Moderate Permeability Sample



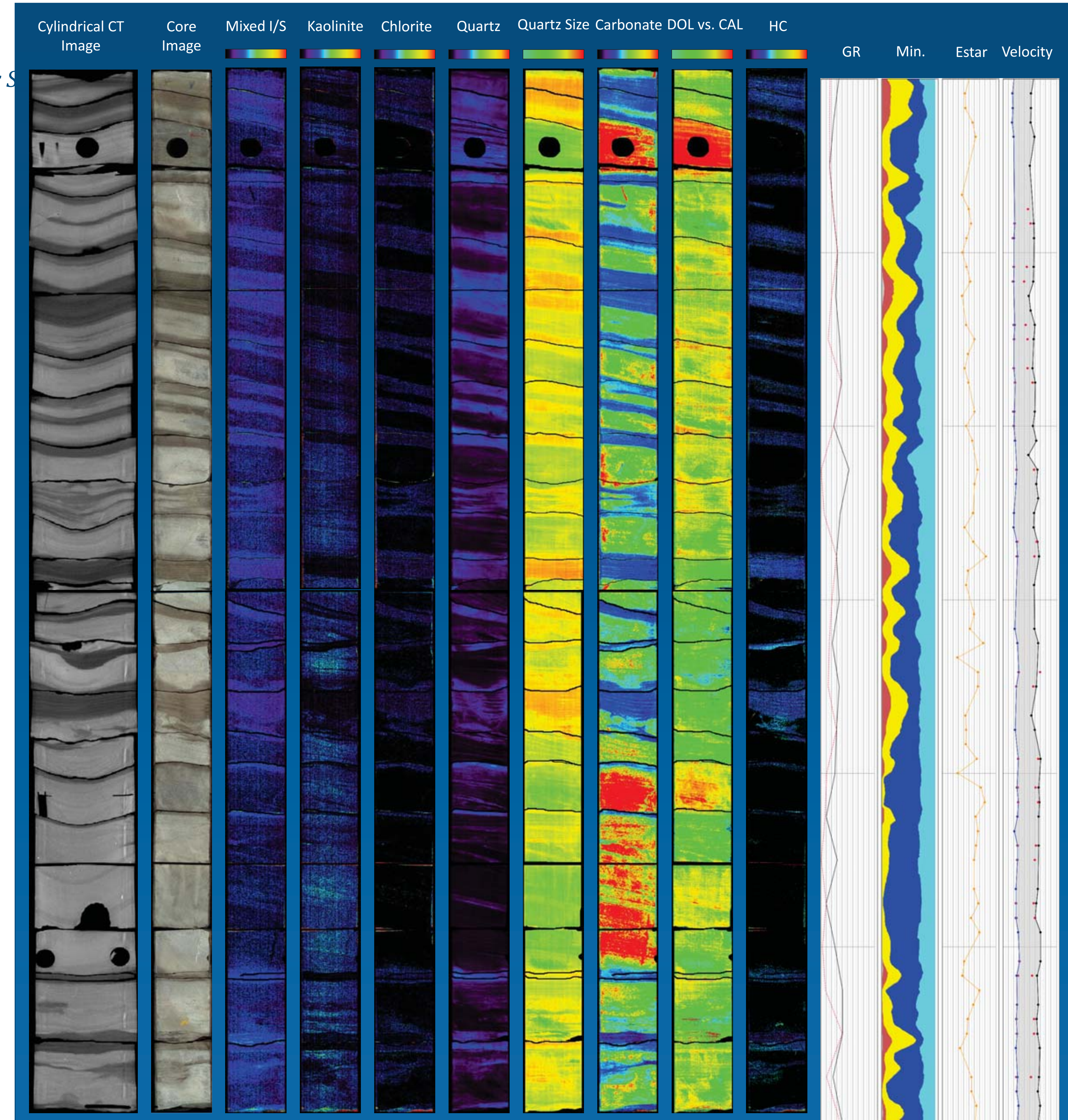
(a) 250x magnification (b) 2000x magnification (c) 2000x magnification (d) 2000x magnification

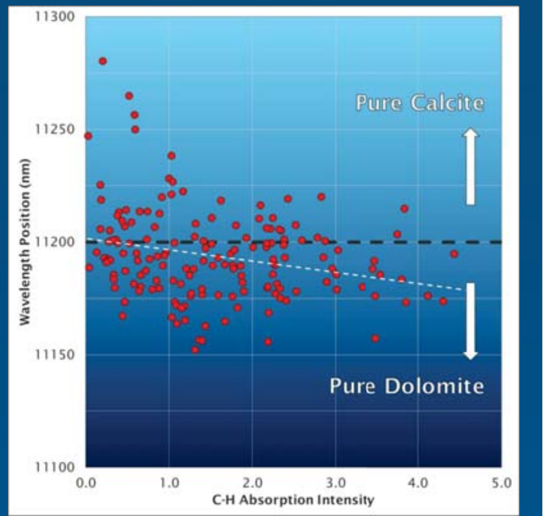
High Permeability Samples

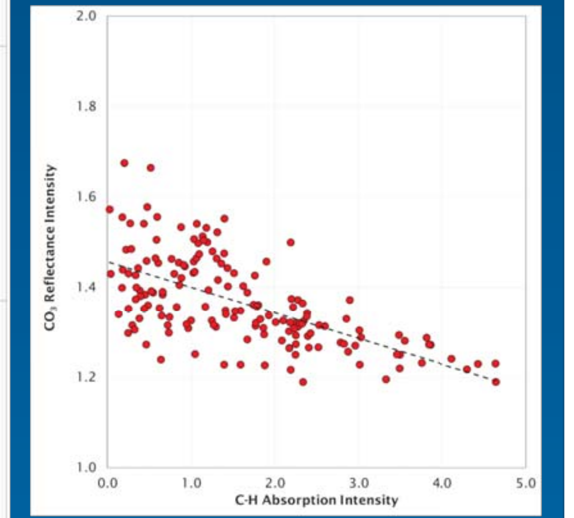


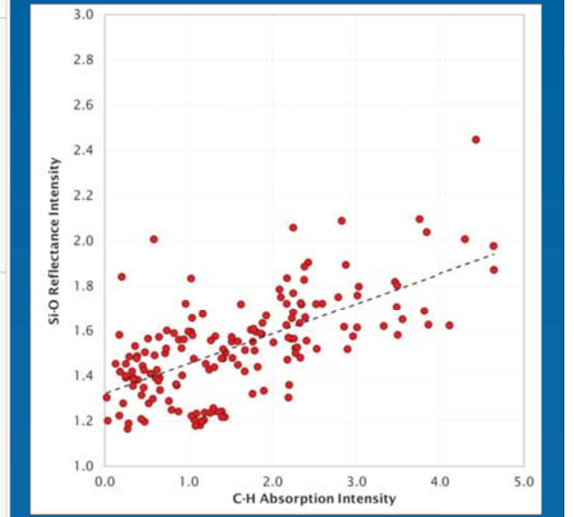
(a) 140x magnification (b) 500x magnification (c) 600x magnification (d) 4000x magnification

Above: Argon ion-milled back scattered SEM analyses of middle Bakken low, moderate, and high permeability samples *(Kurtoglu, 2013).*









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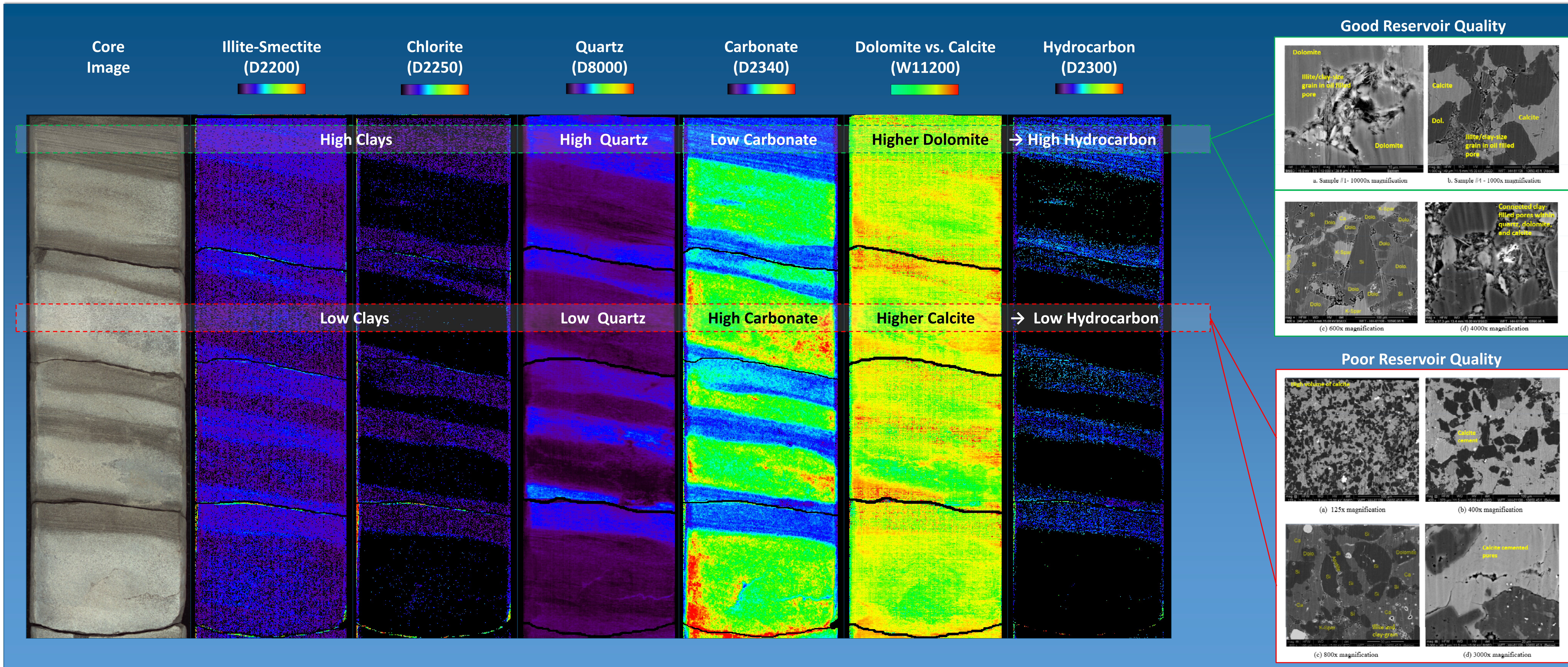

Conclusions

- Porosity in the interbedded siltstone interval of the middle Bakken is preserved within the clay-rich laminations. Oil is stored in the pores of the clay-rich laminations, residing in the spaces between clay lathes and around dolomite rhombs.
- Pores in the carbonate-rich laminations are occluded by multiple phases of calcite, dolomite, and ferroan dolomite cement, all degrading reservoir quality.
- Observations of visible porosity in the carbonate rich laminations in thin sections are likely due to mechanical removal of clays around dolomite rhombs during sample preparation.
- Analysis from Argon-milled SEM samples was necessary to characterize the true porosity of the system.
- The mineral and hydrocarbon maps from hyperspectral imaging confirm that the presence of hydrocarbons is limited to the clay-rich laminations and not present in the carbonate-rich laminations.
- Correlation between SEM analyses and hyperspectral imaging provides rigorous upscaling from micron to core scale.
- Hyperspectral imaging can be a powerful aid in geological and petrophysical 'up-scaling' from SEM- and thin-section scales to depositional-system-level understandings.

References

Kurtoglu, B. (2013) Integrated reservoir characterization and modeling in support of enhanced oil recovery for Bakken, Ph.D. Dissertation, Colorado School of Mines

Acknowledgements

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