Click to view posters (6.4 MB)

PS Hyperspectral Imaging Technology Development and Application; Implications for Thin-Bedded Reservoir Characterization*

Tobi Kosanke[1], Stephanie E. Perry[2], and Ruben Lopez[2]

Search and Discovery Article #42119 (2017)**
Posted August 7, 2017

*Adapted from extended abstract prepared in conjunction with poster presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, April 2-5, 2017

[1]Reservoir Characterization, ALS Oil & Gas, Houston, Texas, United States (Tobi.Kosanke@ALSGlobal.com)
[2]Anadarko Petroleum Company, The Woodlands, Texas, United States

Abstract

Hyperspectral core imaging is a non-destructive analytical technique that determines the mineralogy of a core. Originally developed for the mining industry, hyperspectral imaging uses a combination of short-wave infrared light (SWIR), visible near-infrared light (VNIR), and long-wave infrared light (LWIR) to create a visual 'map' of the minerals in a core that respond to light. This relatively inexpensive technology requires standard slabbed-preparation of the core and produces both image data that shows the textural relationships of the minerals in a core, and digital data that can be imported as curves to display mineralogical variations with depth, much like continuous XRD, alongside petrophysical logs. Hyperspectral core imaging provides detailed, high-resolution mineralogic and textural information of a cored interval that can be used to refine stratigraphic models, explain petrophysical responses, and guide selection of plug locations for conventional and special core analysis. Hyperspectral data can be correlated to petrophysical logs and other continuous- (CT-scan, core Spectral Gamma, etc.) and point-measurement (such as XRD, XRF, rock mechanics, porosity, and permeability) data to help build reservoir models that accurately reflect the compositional and mechanical heterogeneities of a reservoir, potentially leading to more efficient production of hydrocarbons.

Preliminary Case Study

We utilized hyperspectral short-wave and long-wave imaging technologies on ~60 feet of 1/3 section slabbed, whole conventional core from the Permian Basin (FENIX camera). The opportunity allowed technical comparison and development of hyperspectral imaging from multiple wavelength frequencies on non-cylindrical remaining rock volume, opening up the application for many purposes in field study application (geological and petrophysical property associations). This technique can be applied rapidly and provides mineralogical results related to various energy emitted in wavelength spectrum by either halogen bulb reflectance (short-wave quantification) or heat reflectance spectra (long-wavelength quantification) (Figure 1). The heat reflectance technique is non-destructive and does not heat the core above a temperature at which hydrocarbons could be destroyed.

The wavelengths quantified can then be associated with specific mineral assemblages, falling into sub-categories of non-silicates and silicates (Figure 2). The hyperspectral imaging interpreted by short-wave quantification forces a non-silicate to silicate solution and is therefore best applied on clastic-dominated systems. The short-wavelength data has less dependency on crystallographic orientation/structure variation or grain size changes but the longwave data discerns differences in grain size (Figure 3).

Long wavelength hyperspectral imaging allows the additional quantification of clay-and carbonate specification. Feature extractions are a measure of the strength of heat emissivity (long-wavelength), or light reflectance (short-wavelength) adding intensity extraction based on the RGB light spectrum for further hyperspectral ‘fingerprinting’ along the length of a scanned sedimentologic core.

The application of this technology as presented in this study resulted in impactful mineralogical to petrographic integration then associating stratigraphic context with a depositional environmental framework (Figure 4). The mineral assemblages that can be texturally associated via the whole core links the fine-scaled thin section analysis that the industry has relied on in the past, to an up-scaled representation of the overall geological system (Figure 5). The technology can then be compared to various quantified properties and links between geologic property-based driver’s better understood (Figure 6 and Figure 7).

The above integration shows decent agreement with wireline based three-mineral model interpretation with derived ‘clay’ and ‘quartz’ values from hyperspectral imaging. Additional core imagery generated from short wavelength infrared analysis next to resistivity borehole imaging and open-hole wireline based rock typing models allows perspective on a multi-scale challenge in hybrid play systems. Accounting for thinly-bedded variability below standard open-hole wireline vertical resolution (~2 feet) aids in sedimentologic-to petrophysical upscaling characterization. Hyperspectral imaging allows the petrophysicist to understand what is physically being ‘lumped’ by the finest-resolution models they can apply (limited by open-hole wireline vertical resolution).

On the white light photography we can begin to visually identify transitions in bedding associations related to changes in the depositional systems providing sediment into the basin. As we compliment that photography with short-and long wavelength imaging we gain textural associations not visually identified or distinguished. Typically, our textural understanding would be gained from thin section photomicrographs at a mm-cm scale of understanding, then requiring assumptions to how these very detailed observations can be ‘up-scaled’ to whole core and open hole wireline representation. Now we can physically begin to link and gain confidence in the ‘up-scaled’ sedimentologic and petrophysical property associations.

Summary

- Advances in hyperspectral imaging are being made in the industry that allow the quantification of mineral speciation via short-and long wavelength light spectra.

- Applied as an integrative tool, additional whole core imagery can begin to aid in geological and petrophysical quantification and property ‘up-scaling’ from microns to depositional system understandings.

- Integration across additional data streams can begin to link geological and property drivers with stratigraphic context where applicable.

Reference Cited

Perry, A., S. Perry, I. Mathews, and J. Market, 2017, Unraveling the Acoustic Challenges in Horizontal Wellbore Environments – A Case Study in the Delaware Basin: Abstract, SPWLA 58th Annual Logging Symposium, Society of Petrophysicists and Well-Log Analysis, 17-21 June 2017, Oklahoma City, Oklahoma, p. 185.

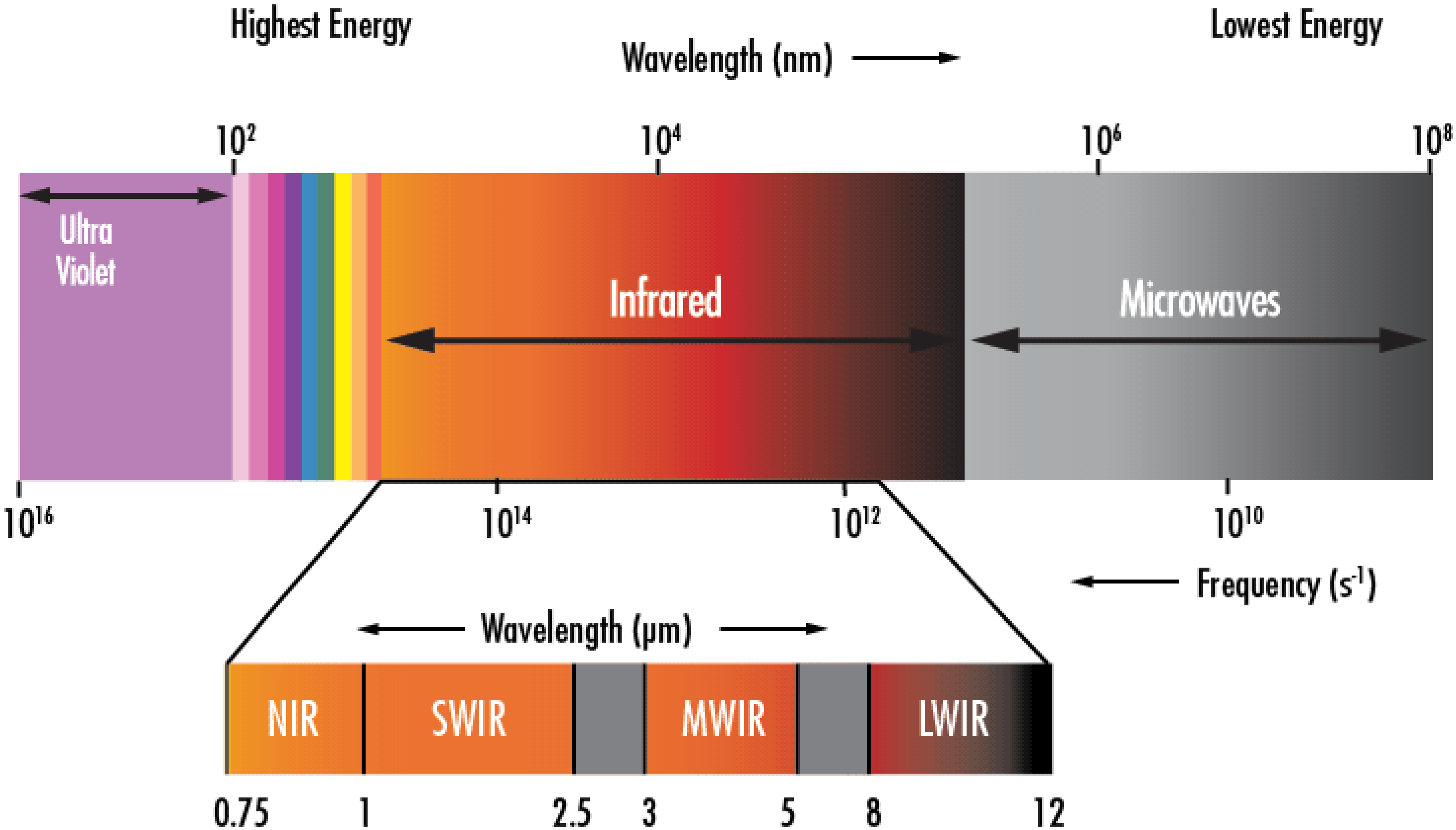

Figure 1. Schematic of energy spectrum captured by short and long wavelength resolution hyperspectral imaging technique.

Type	Silicate Structure	Mineral Group	Example	VNIR Response	SWIR Response	LWIR Response
Silicates	Inosilicates	Amphibole	Actinolite	Non-Diagnostic	Good	Moderate
Silicates	Inosilicates	Pyroxene	Diopside	Good	Moderate	Good
Silicates	Cyclosilicates	Tourmaline	Elbaite	Non-Diagnostic	Good	Moderate
Silicates	Nesosilicates	Garnet	Grossular	Moderate	Non-Diagnostic	Good
Silicates	Nesosilicates	Olivine	Forsterite	Good	Non-Diagnostic	Good
Silicates	Sorosilicates	Epidote	Epidote	Non-Diagnostic	Good	Moderate
Silicates	Phyllosilicates	Mica	Muscovite	Non-Diagnostic	Good	Moderate
Silicates	Phyllosilicates	Chlorite	Clinochlore	Non-Diagnostic	Good	Moderate
Silicates	Phyllosilicates	Clay Minerals	Illite	Non-Diagnostic	Good	Moderate
Silicates	Phyllosilicates	Clay Minerals	Kaolinite	Non-Diagnostic	Good	Moderate
Silicates	Tectosilicates	Feldspar	Orthoclase	Non-Diagnostic	Non-Diagnostic	Good
Silicates	Tectosilicates	Feldspar	Albite	Non-Diagnostic	Non-Diagnostic	Good
Silicates	Tectosilicates	Silica	Quartz	Non-Diagnostic	Non-Diagnostic	Good
Non-Silicates	Carbonates	Calcite	Calcite	Non-Diagnostic	Moderate	Good
Non-Silicates	Carbonates	Dolomite	Dolomite	Non-Diagnostic	Moderate	Good
Non-Silicates	Hydroxides		Gibbsite	Non-Diagnostic	Good	Moderate
Non-Silicates	Sulphates	Alunite	Alunite	Moderate	Good	Moderate
Non-Silicates	Sulphates		Gypsum	Non-Diagnostic	Good	Good
Non-Silicates	Borates		Borax	Non-Diagnostic	Moderate	?
Non-Silicates	Halides	Chlorides	Halite	Non-Diagnostic	?	?
Non-Silicates	Phosphates	Apatite	Apatite	Moderate	Non-Diagnostic	Good
Non-Silicates	Hydrocarbons		Bitumen	?	Moderate	?
Non-Silicates	Oxides	Hematite	Hematite	Good	Non-Diagnostic	Non-Diagnostic
Non-Silicates	Oxides	Spinel	Chromite	Non-Diagnostic	Non-Diagnostic	Non-Diagnostic
Non-Silicates	Sulphides		Pyrite	Non-Diagnostic	Non-Diagnostic	Non-Diagnostic

Figure 2. Example explanatory demonstrating the mineral detection capabilities of each wavelength specific range.

Figure 3. Short wavelength hyperspectral imaging on 1/3 slabbed-conventional core from the Permian Basin. The short wavelength region (>1000-2500nm) has been utilized by the coal and mining industry for ~30 years.

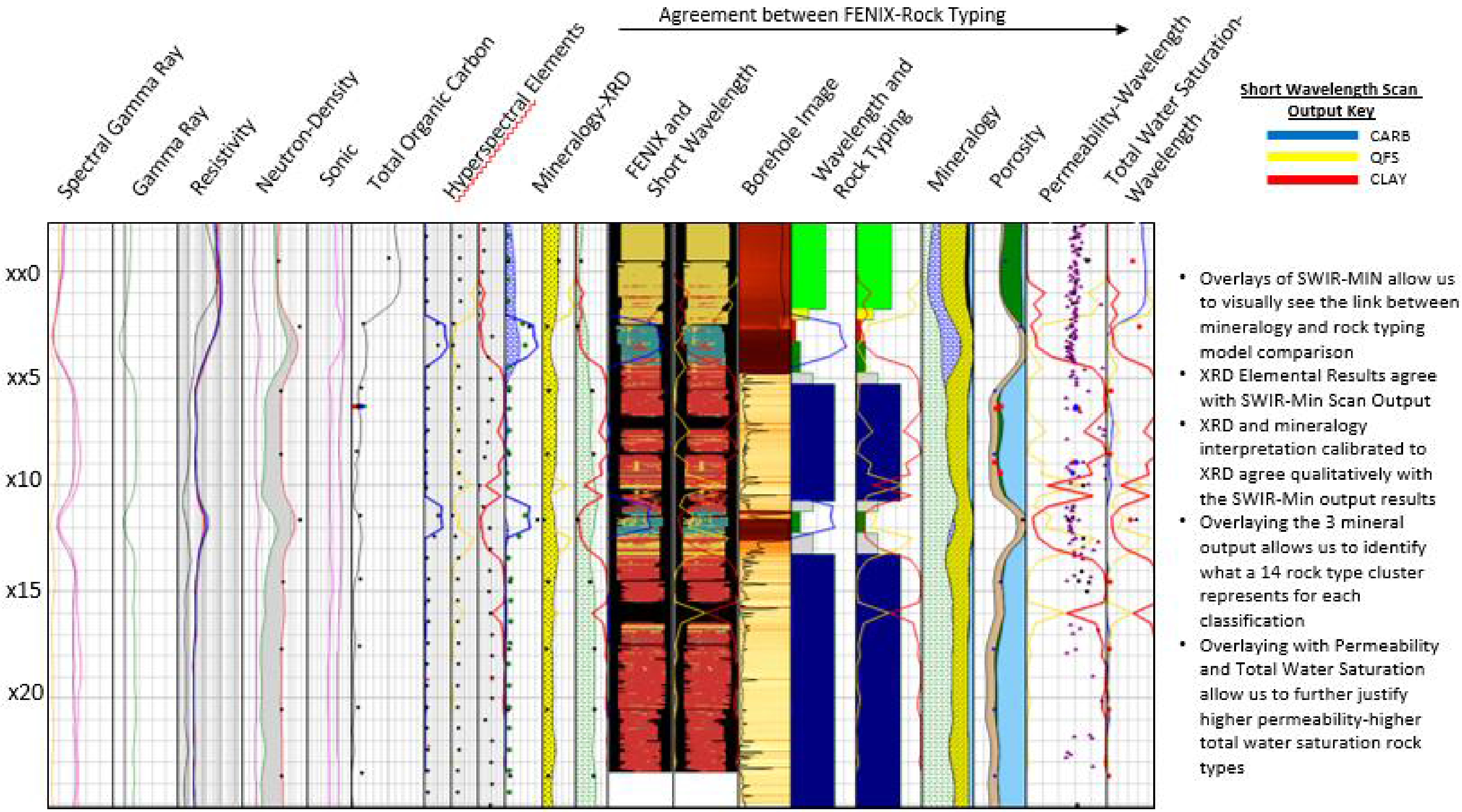

Figure 4. Integrative association of open hole wireline properties, interpreted mineralogical assemblages from short-wave infrared hyperspectral scanning and quantification, rock typing model with mineralogical associations overlays, and petrophysical property co-location for better understanding of mineralogical to petrophysical links.

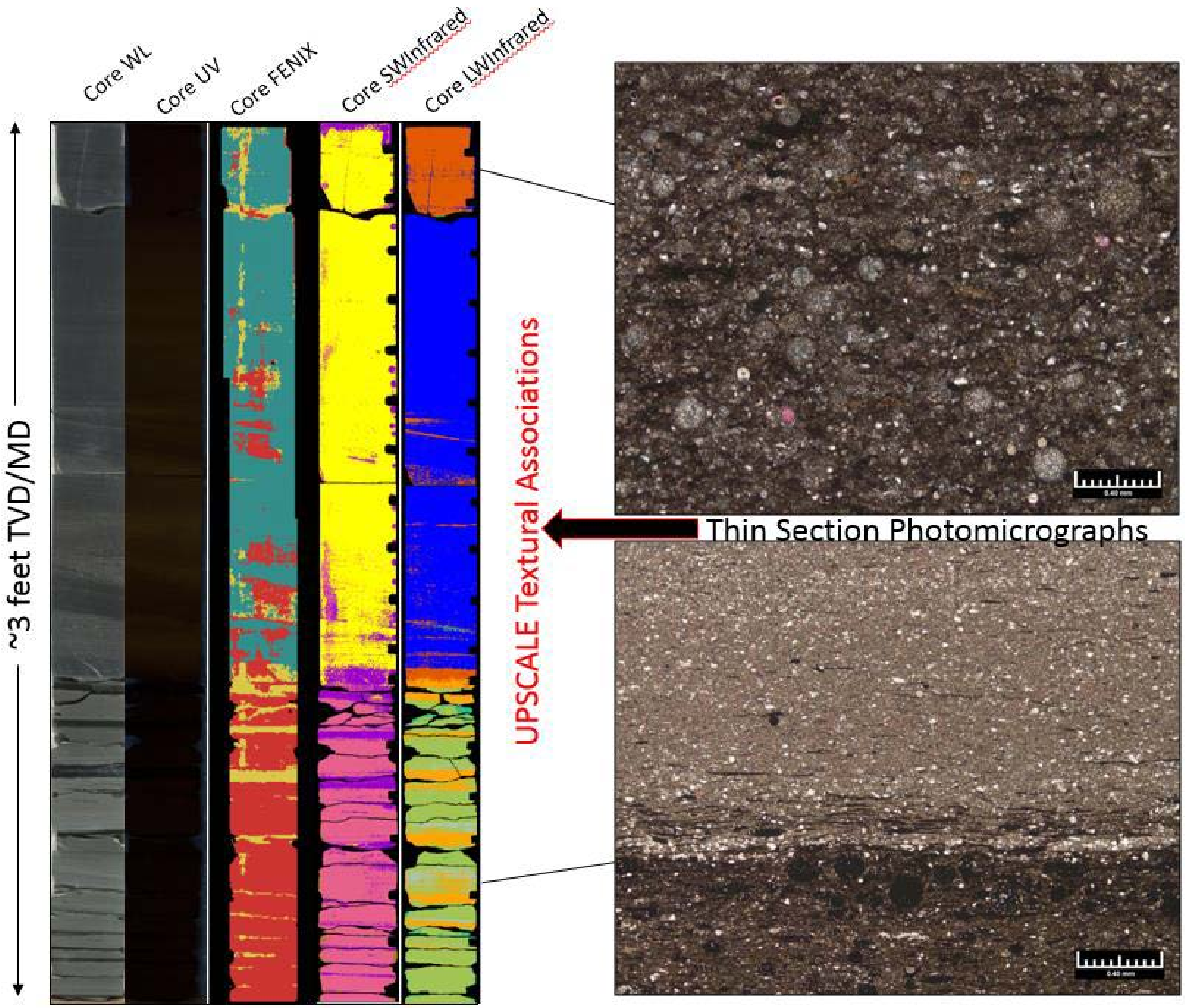

Figure 5. Transitional understanding that can be gained from looking at applied technologies beyond the standard white light and ultraviolet light photographs of 1/3 slabbed whole core.

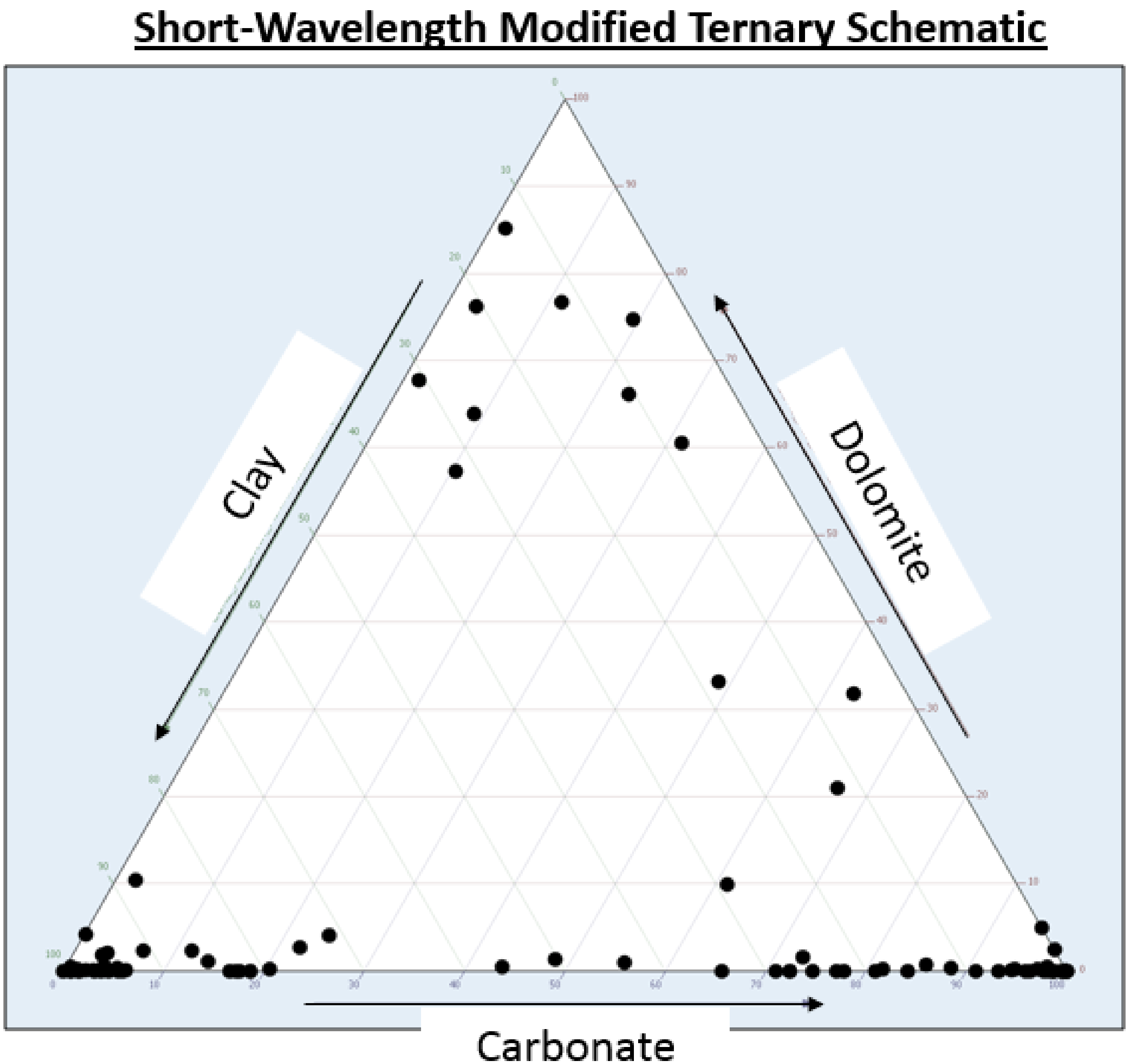

Figure 6. Modified Ternary diagram to represent mineralogical content in relation to Silicates-Clays and remaining Carbonate in the genetic system.

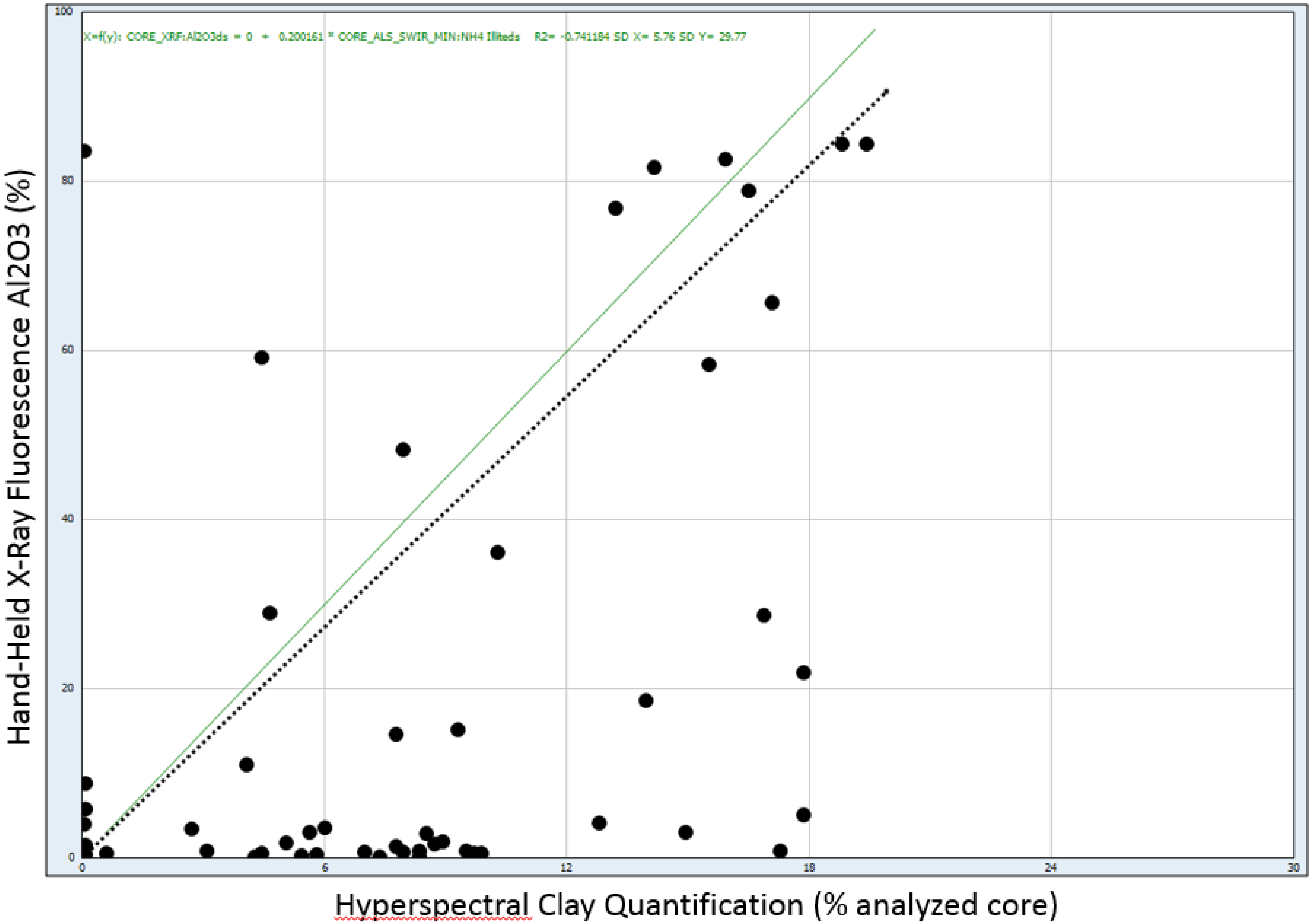

Figure 7. Cross-plot between percent of quantified clay over the 1/3 slab face of a core compared to measured hand-held x-ray fluorescence Al_2O_3 (%) oxide quantification. Positive correlation with spatially limited representation of the depositional system, therefore field wide application may lead to dual associations or regressions more robustly linking whole core scale mineralogy to basin-wide context.