PSUtilization of High-Resolution Short- and Long-Wave Hyperspectral Imaging for Integrative Rock Typing*

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Abstract

Hyperspectral imaging (HI) is a method of observing and enhancing geological rock properties that are not readily apparent visually. Originally developed for the mining industry for use in airborne systems, HI uses a combination of short-wave infrared light (SWIR) and long-wave infrared light (LWIR) to create a visual 'map' of the minerals on the surface of a core that respond to reflectance principles. Although bespoke hyperspectral imaging systems have now been developed and utilized to great success in the mining industry to map mineralogical changes along a core, the technology has been limited to the SWIR region (<2500 nm), and important minerals in oil and gas reservoirs, such as quartz and feldspar, cannot be detected in those wavelengths. Until very recently, commercial imaging technology for the LWIR has not been available due to cost and technical challenges. The relatively new LWIR spectrometer, which contains a specialized lens to obtain data at a high resolution of 300-500 µm per pixel, measures responses from tectosilicates, carbonates and some clays, as well as hydroxides, sulfates, and phosphates. Processing of the HI data involves the generation of two sets of self-organizing map (SOM) classifications, one for each of the SWIR and LWIR sensors. SOM is a type of unsupervised artificial neural network, which is an effective classification method to classify non-linear data with a large number of variables by calculating minimum distances between the data points. Each acquired pixel on the core surface is associated with a SOM class from the SWIR and LWIR sensors. We have developed a method that utilizes these raw (uninterpreted) SOM data to produce rock types for cores from both silicate and carbonate formations. These rock types have been generated for a variety of conventional and unconventional reservoirs to guide sampling for plug locations for conventional and special core analysis. We present examples of how HI-derived rock types have been combined with a variety of core data, including core description, thin-section, X-Ray Fluorescence (XRF) data and X-Ray Diffraction (XRD) data to produce impactful mineralogical integration within a stratigraphic context.

Selected References

Alnahwi, A., T. Kosanke, R. Loucks, J. Greene, X. Liu, and P. Linton, 2019, High-resolution Hyperspectral-based Continuous Mineralogical and TOC Analysis of the Eagle Ford Group and Associated Formations in South Texas: AAPG Bulletin (*in publication*).

ElMasry, G., and D.-W. Sun, 2010, Principles of Hyperspectral Imaging Technology, *in* D.-W. Sun (ed.), Hyperspectral Imaging for Food Quality Analysis and Control: Academic Press, Elsevier, London, p. 3-43.

Greene, J., T.H. Kosanke, and P. Linton, 2019, 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: 2019 AAPG Annual Convention and Exhibition, San Antonio, Texas, May 19-22, Search and Discovery Article #42444 (2019). Website accessed September 2019.

Hunt, G.R., J.W. Salisbury, and C.J. Lenhoff, 1973, Visible and Near Infrared Spectra of Minerals and Rocks. VI. Additional Silicates: Modern Geology, v. 4, p. 85-106.

Kosanke T.H., and J. Chen, 2017, Hyperspectral Imaging: Geological and Petrophysical Applications to Reservoir Characterization: Unconventional Resources Technology Conference, Austin, TX. doi10.15530-urtec-2017, 2670537

Kosanke, T.H., S.E. Perry, and R. Lopez, 2017, Hyperspectral Imaging Technology Development and Application; Implications for Thin-Bedded Reservoir Characterization: AAPG 2017 Annual Convention and Exhibition, Houston, Texas, April 2-5, 2017, Search and Discovery Article #42119 (2017). Website accessed September 2019.

Murphy, R.J., and S.T. Monteiro, 2013, Mapping the Distribution of Ferric Iron Minerals on a Vertical Mine Face using Derivative Analysis of Hyperspectral Imagery (430–970nm): ISPRS Journal of Photogrammetry and Remote Sensing, v. 75, p. 29–39.

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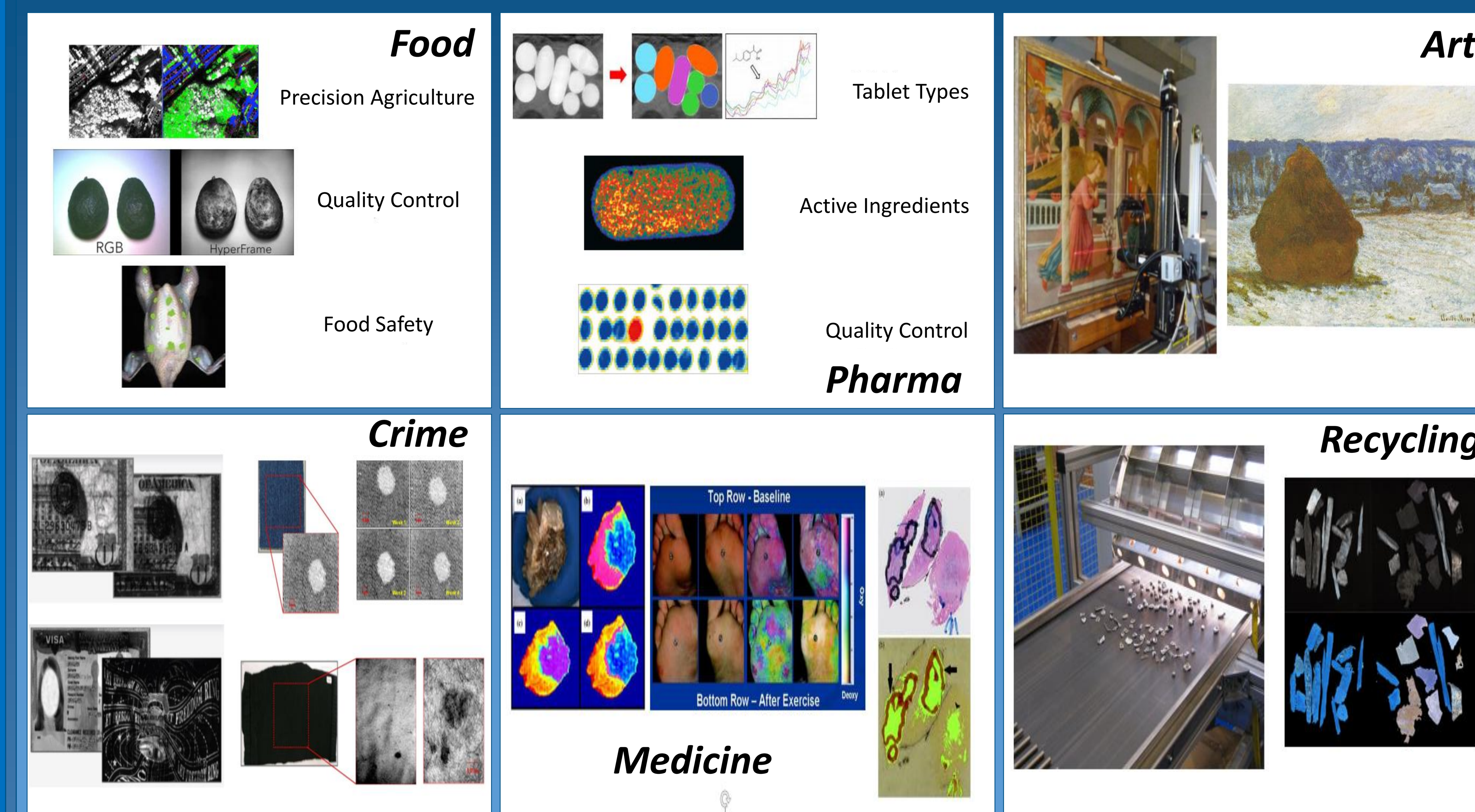
Hyperspectral Imaging System

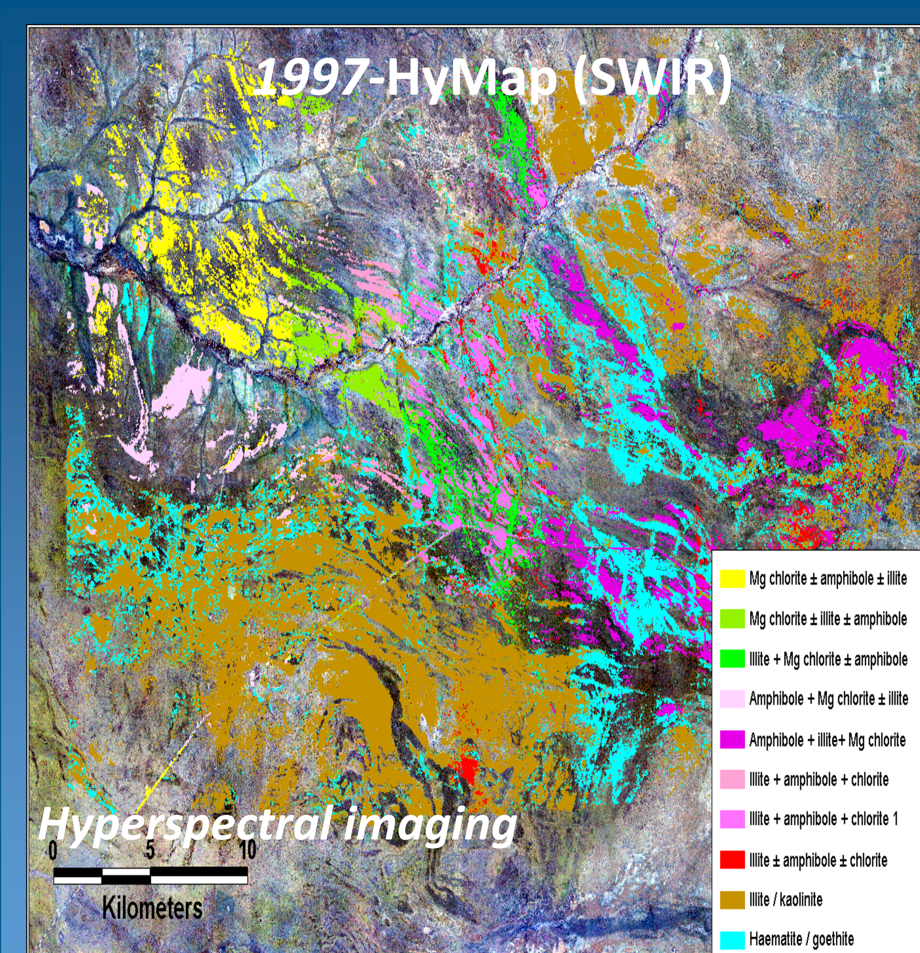
Three spectrometers in succession (RGB, SWIR, LWIR) are used to acquire spectral data

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



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

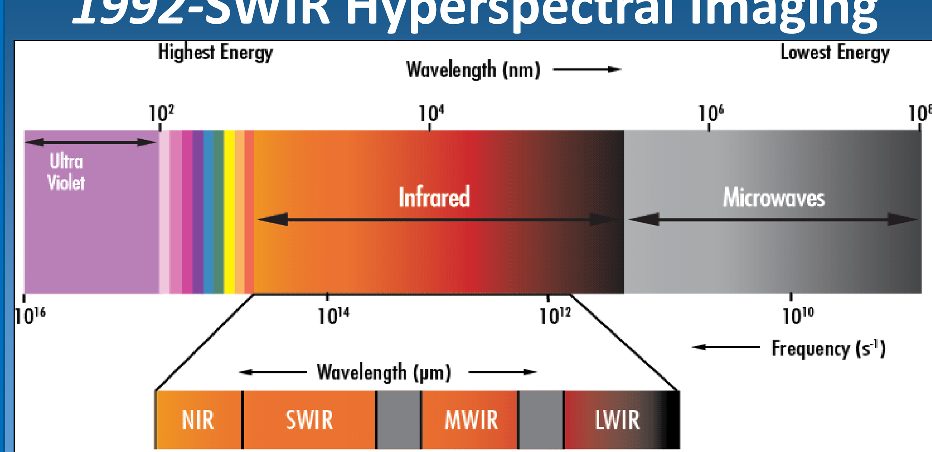
AVIRIS airborne hyperspectral instrument owned and operated by NASA for research. HyMap instruments appear as one of first commercial airborne systems, followed by SpecIm and Norsk Elektro Optik.



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

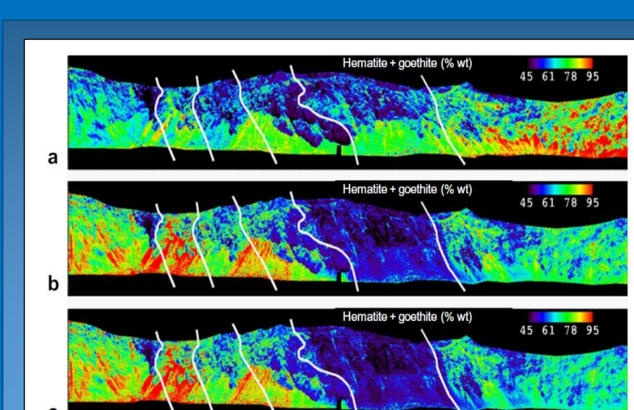
Upgraded Landsat satellite systems with better spatial and spectral resolution (10-30m)

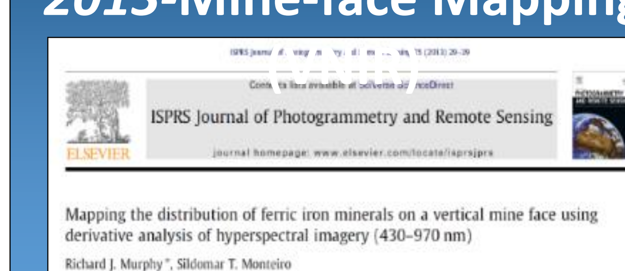


High spatial resolution satellites (Quickbird and Ikonos)

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

2013-Mine-face Mapping

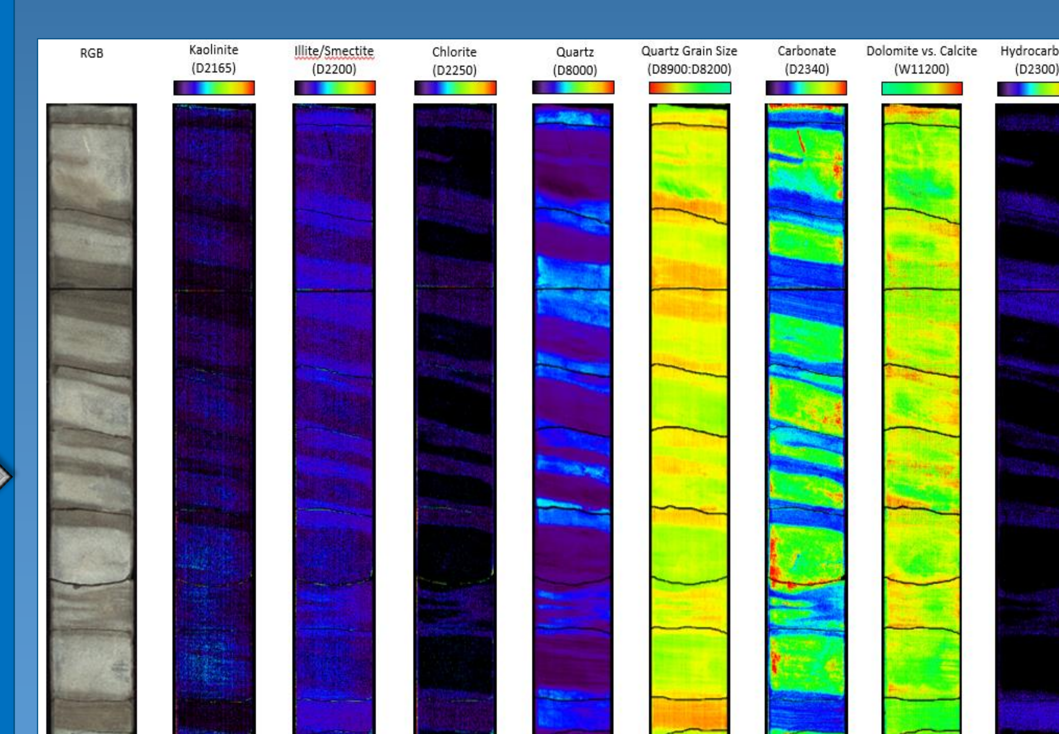


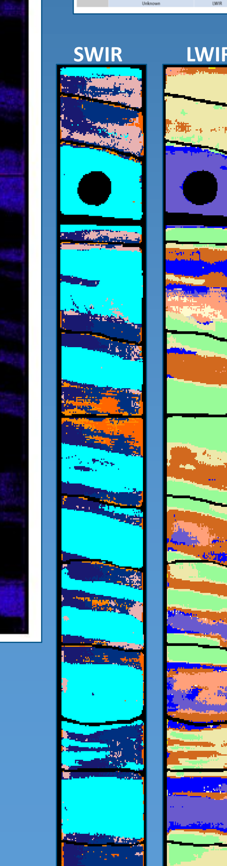


Introduction of high-resolution shortwave (SWIR) and longwave (LWIR) hyperspectral imaging of core

Terracore High-Resolution Hyperspectral Imaging of Core (SWIR and LWIR)

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





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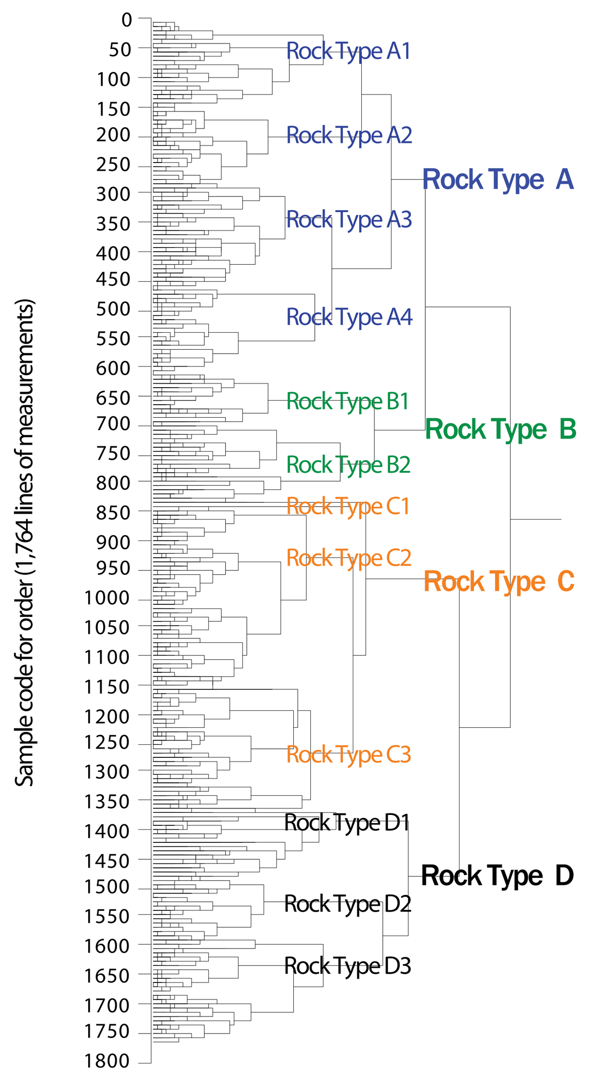
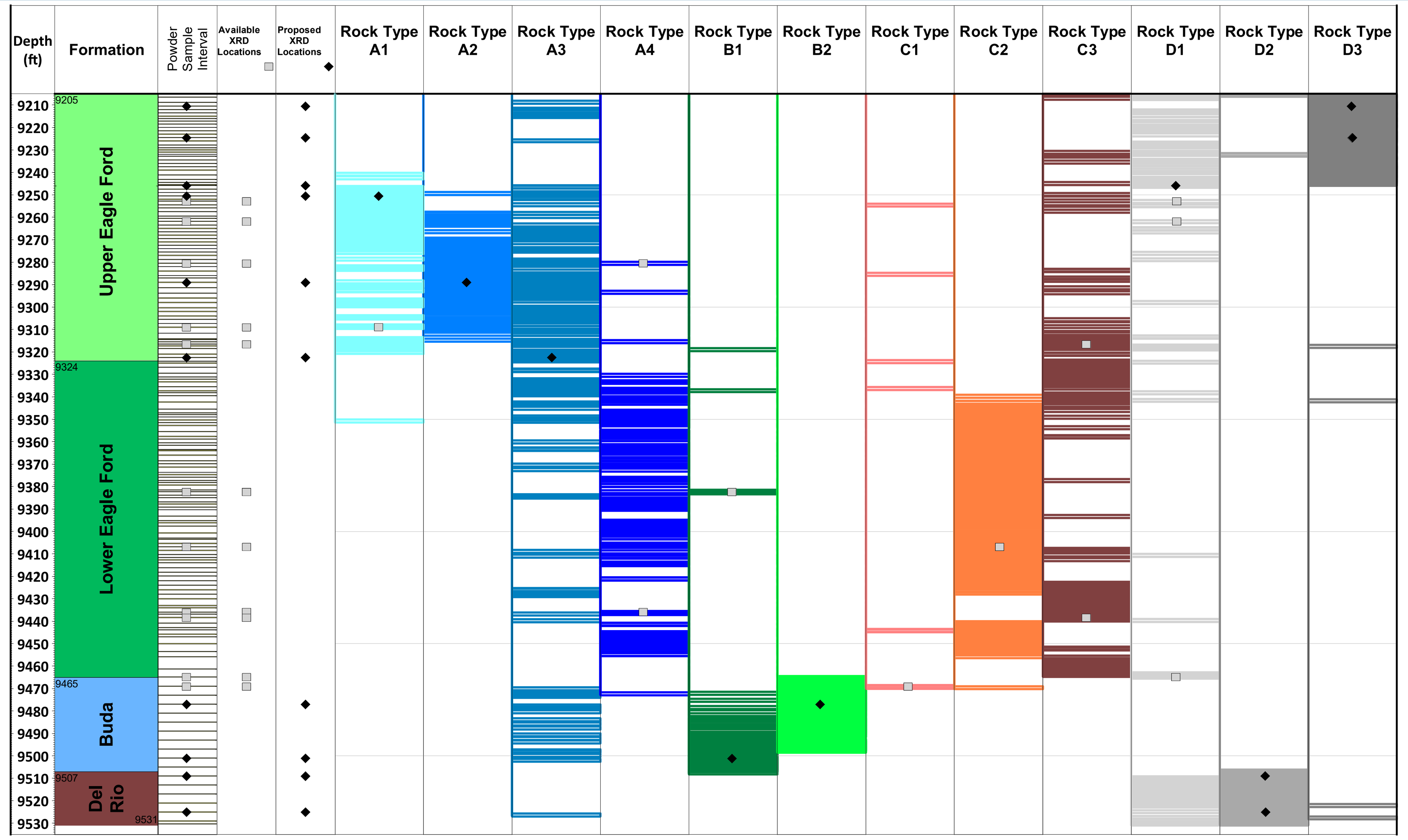
Cluster using combined data of HI and XRF





Sample Number	Depth	Proposed XRD / Available XRD	Rock Type
#1	9210.583	X	D3
#2	9224.583	X	D3
#3	9245.917	X	D1
#4	9250.583	X	A1
	9252.917	X	D1
	9261.917	X	D1
	9280.583	X	A4
#5	9289.083	X	A2
	9309.083	X	A1
	9316.583	X	C3
#6	9322.583	X	A3
	9382.417	X	B1
	9406.917	X	C2
	9436.083	X	A4
	9438.417	X	C3
	9464.917	X	D1
	9469.083	X	C1
#7	9477.083	X	B2
#8	9501.083	X	B1
#9	9509.083	X	D2
#10	9525.083	X	D2

Case Study

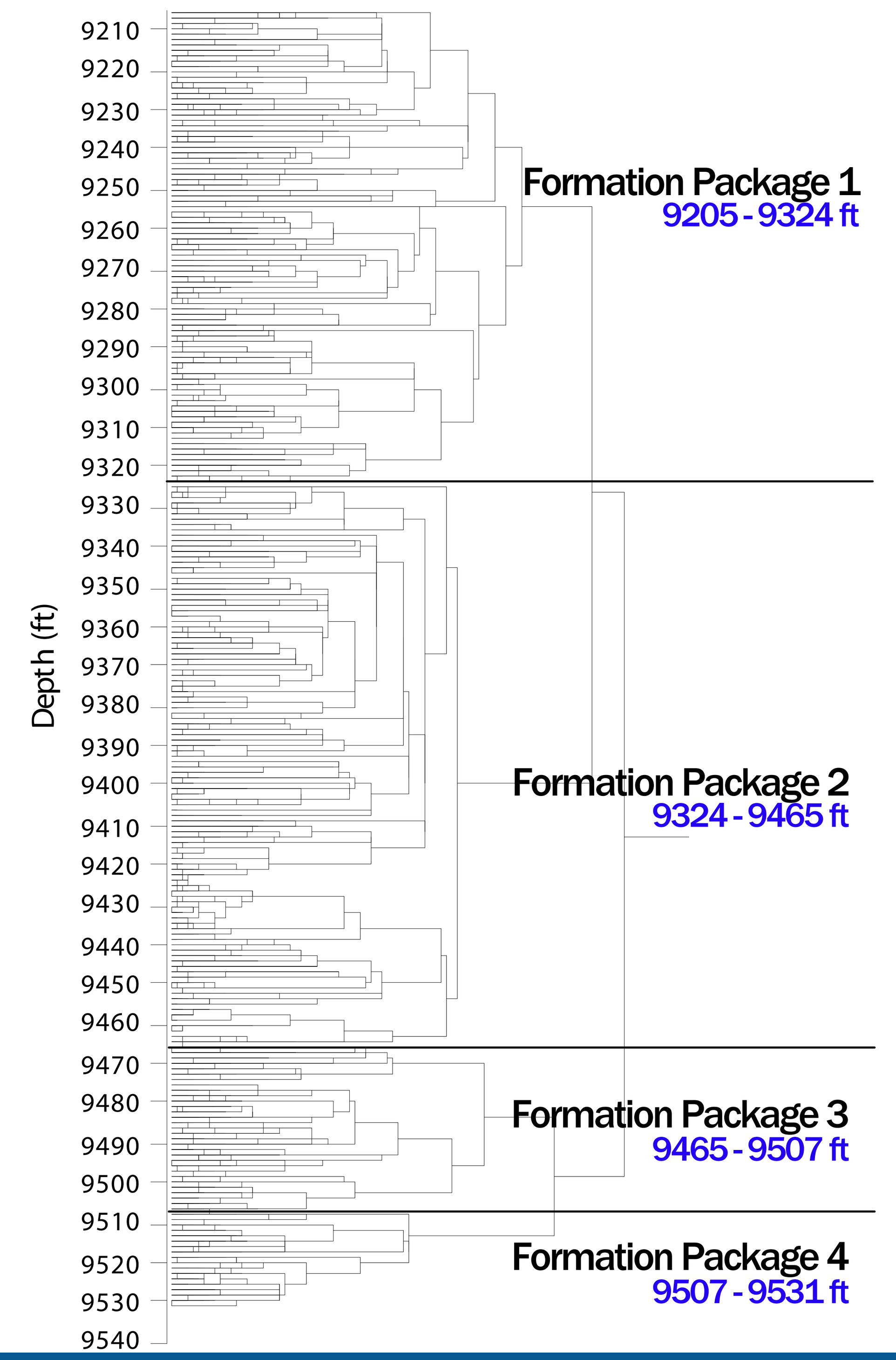
Here we present a case study to demonstrate how to utilize HI raw SOM data for integrative rock typing. The ~325 ft cores are from the Eagle Ford formation. HI data were collected at a resolution of 0.01 ft. Hand-held XRF data were collected at a resolution of 0.17 ft. The details of this study are available in Alnahwi et al. 2019.

Upper right panel: four rock types and twelve rock sub-types are determined using a classical clustering method. The rock types are used to guide XRD sampling.

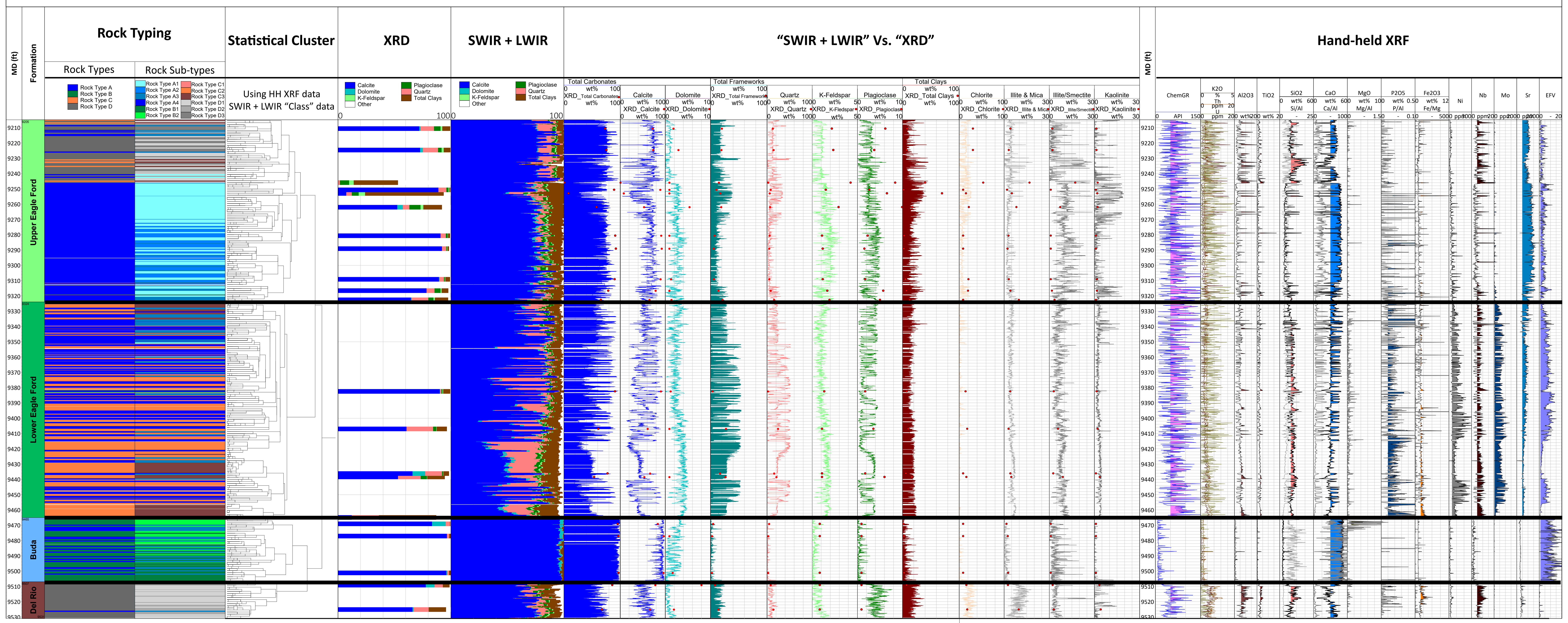
Lower right panel: the integrated logs include rock typing results, XRD mineral compositions, HI calibrated mineral compositions, and hand-held XRF data.

Reference:
High-resolution Hyperspectral-based Continuous Mineralogical and TOC Analysis of the Eagle Ford Group and Associated Formations in South Texas. Ahmed Alnahwi, Tobi Kosanke, Robert Loucks, James Greene, Xiuju Liu, and Paul Linton. 2019. AAPG Bulletin, in publication.

Depth Constrained cluster using combined data of HI and XRF



Example of Rock Typing_Integrated Chart



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Summary and Conclusions

- We have developed a method that utilizes raw (uninterpreted) SOM data to produce rock types for cores from both silicate and carbonate formations.
- The HI "rock types" are statistically driven rock types that share similar elemental and spectral responses.
- We presented a case study to demonstrate how to utilize HI raw SOM data for integrative rock typing.
- HI-derived rock types were combined with a variety of core data, including X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD) data to produce impactful mineralogical integration within a stratigraphic context.
- The rock types can be used to guide and optimize XRD sampling, with the number of clusters selected subjectively to fit the project budget.
- In future, we plan to evaluate the use of the mid-range infrared light (MWIR) for rock typing.

References

Alnahwi, A., T. Kosanke, R. Loucks, J. Greene, X. Liu and P. Linton, 2019, AAPG Bulletin (*in publication*).

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