Lithology and mineralogy of the Upper Cretaceous Niobrara Formation examined by hyperspectral core imaging

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U.S. Department of the Interior
U.S. Geological Survey

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Overview

The Niobrara Formation is one of the most important plays areas in the western United States.

Niobrara cores collected in central Colorado and western Kansas. These cores are housed at the USGS Core Research Center and are in high demand for viewing and sampling.

A large volume of geochemical data has been obtained for these cores by USGS researchers or donated by various operators.

Facies transitions across Fort Hays Limestone into the Smokey Hills Chalk are clearly delineated in these cores, along with features like the OAE-3.

The results of this hyperspectral core scanning and imaging project provide a high-resolution digital record that includes detailed information on the type and distribution of minerals and lithologies present in the Niobrara Formation.

USGS

Project Background

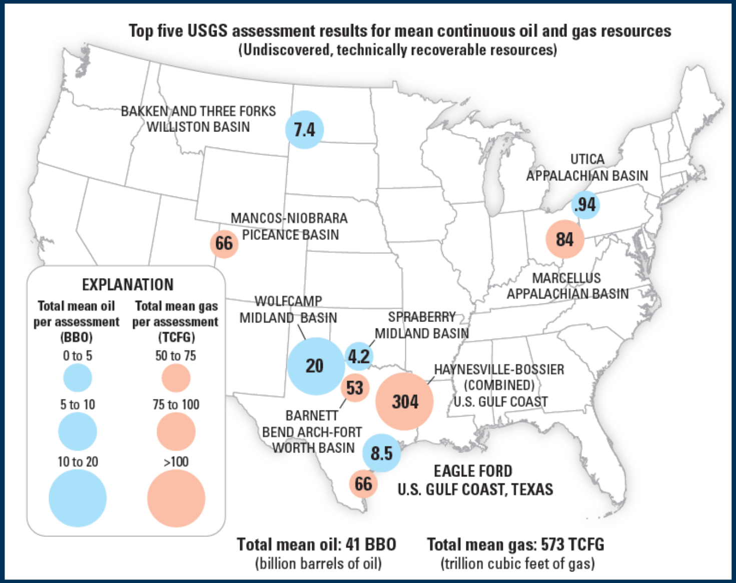
In September 2015, Corescan installed a mobile laboratory at the USGS Core Research Center in Denver, CO

Scanning was performed for 30 days

Thirty (30) separate projects were acquired for a total of ~8,670 ft

Projects/core were selected by:
Crustal Geophysics & Geochemistry
Energy
Minerals
Core Research Center

Project Background



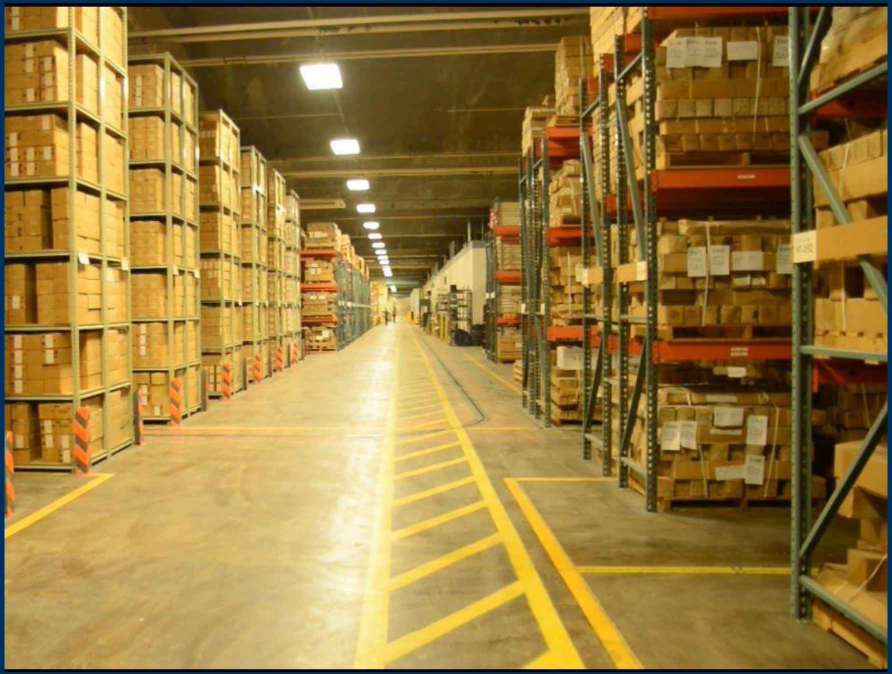
Petroliferous mudrock core from important U.S. petroleum systems were scanned for the Energy Resources Program. **This work supports the research that underpins USGS geologic assessments of undiscovered, technically recoverable oil and gas resources.**

GOALS:

Explore high-resolution spectral imaging of core as an archival tool and make USGS Core Research Center resources more accessible to the public through an electronic archive.

Capture high-resolution mineralogical and lithological information on source rock intervals. Mudrocks vary at multiple scales, from thick stratigraphically correlative intervals (10's to 100's of feet) to fine laminated sequences showing alternating composition at the submillimeter level.

Summary of core scanned for the USGS Energy Resources Program

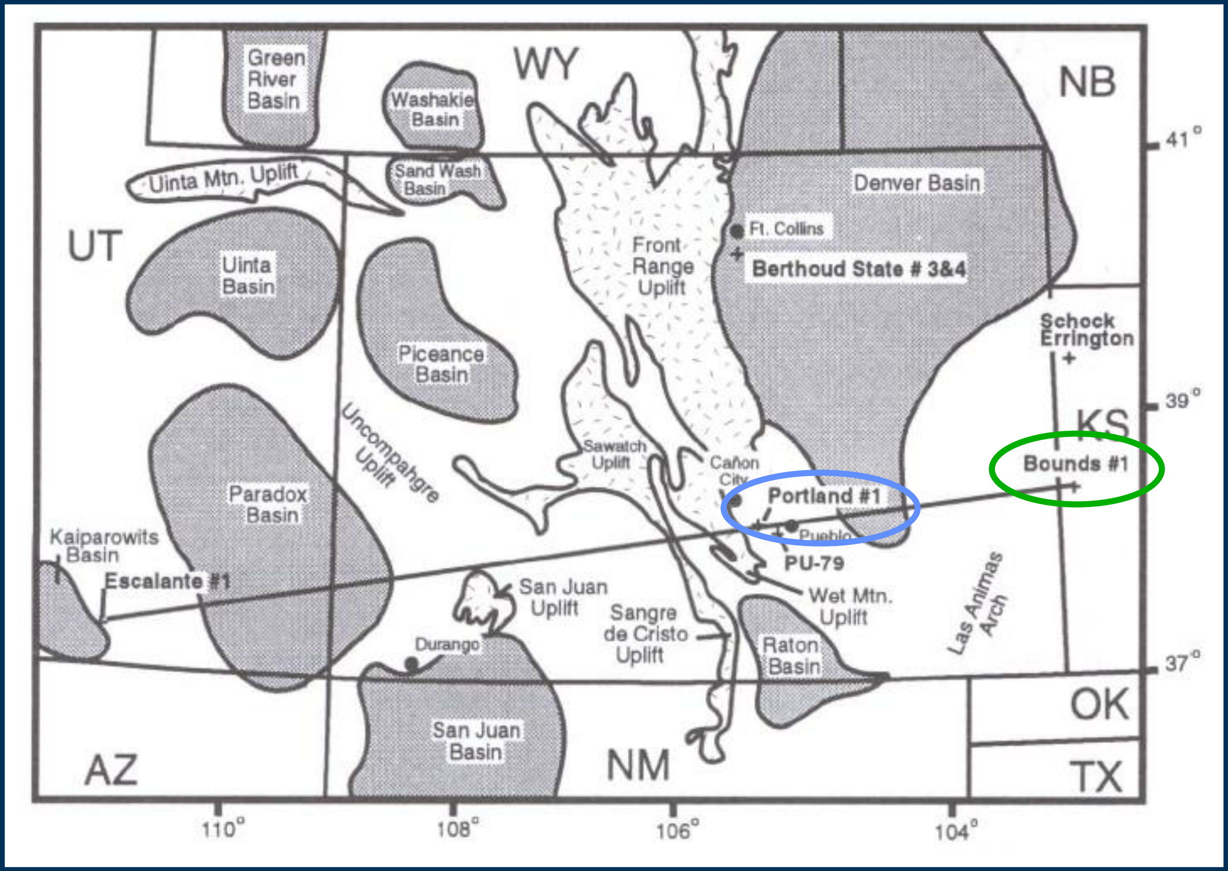


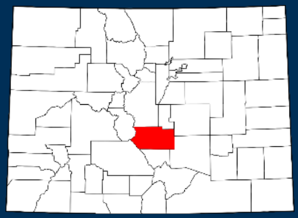
USGS Core Research Center in Denver, CO
https://www.usgs.gov/core-science-systems/nggdp/core-research-center

Core name (formation, state)	Feet
Ikpikpuk (Shublik, AK)	125
1 Phoenix (Shublik, AK)	344
Inigok (North Slope, AK)	130
Inigok north (North Slope, AK)	17
31-1 Figure 4 (Green River, CO)	140
1 Milo Love (Green River, CO)	130
Gulf Coast 1 (Eagle Ford, TX)	600
AB-2-11 (Mancos, CO)	876
HM-1-13 (Mancos, CO)	326
Portland 1 (Niobrara, CO)	680
Rebecca Bounds (Niobrara, KS)	956

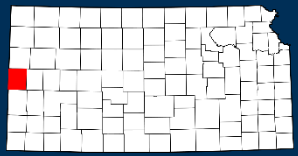
USGS

Core Locations





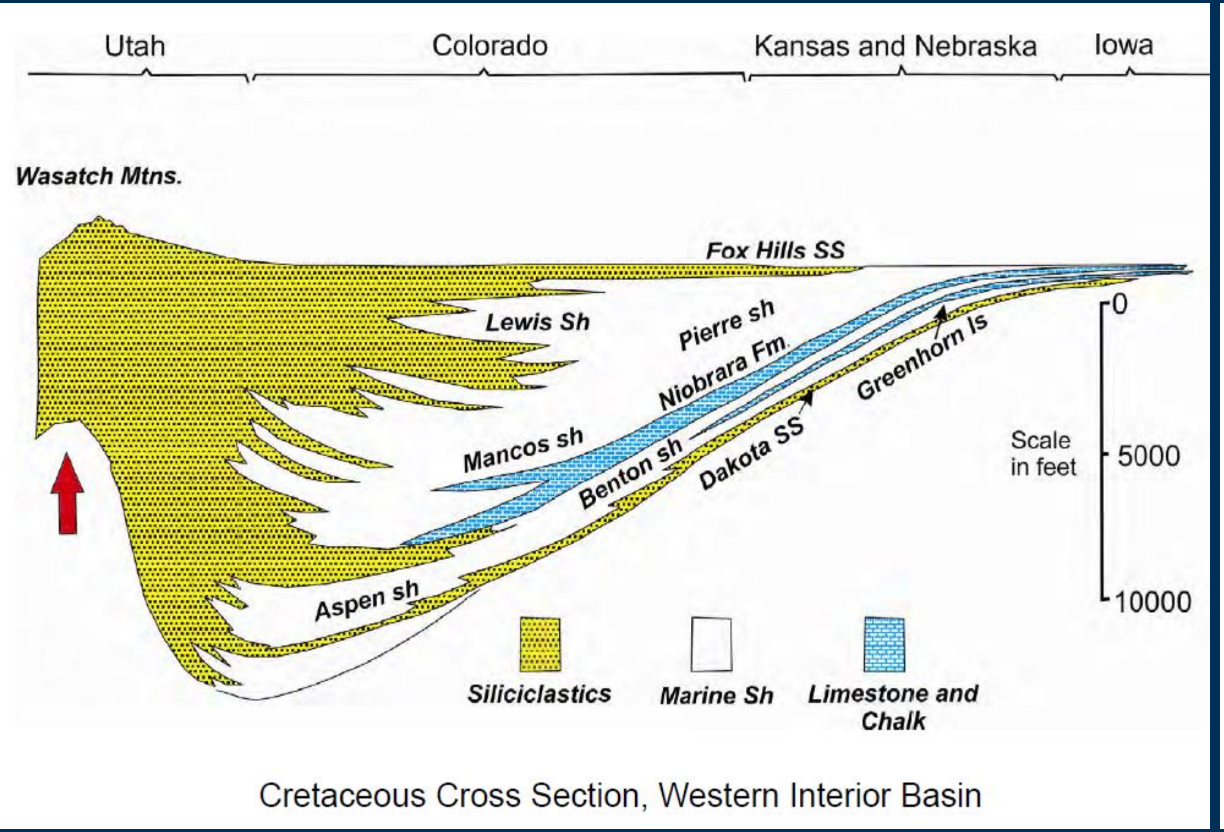
USGS Portland-1

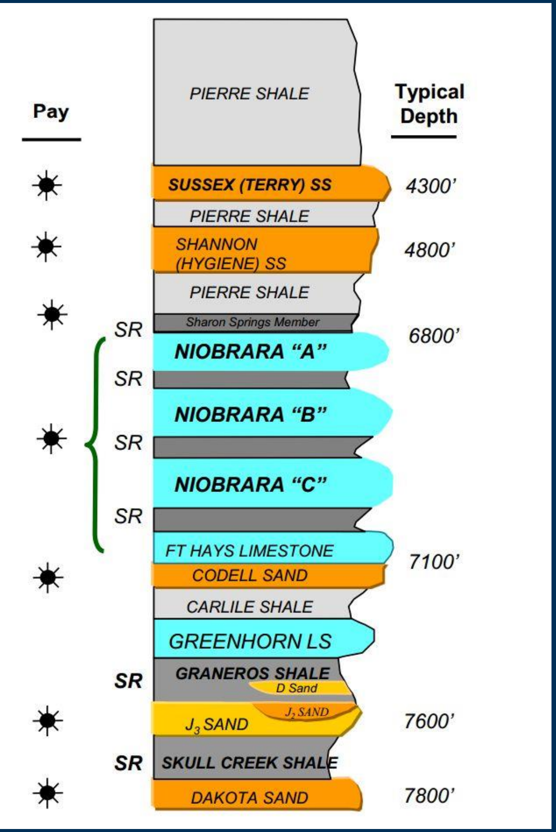


Amoco Rebecca Bounds

Locations of the Amoco Rebecca Bounds and USGS Portland-1 Cores

Summary of Niobrara stratigraphy





Above: Cross section showing the Nobrara Formation across the display area. After Kauffman (1977) prepared by Sonnenberg and Taylor (accessed 2018).

Right: Stratigraphic column showing the Niobrara Formation in the Denver-Julesburg Basin from Sonnenberg (2011).

Summary of Niobrara stratigraphy

C.M. Lowery et al. Earth-Science Reviews 177 (2018) 545–564

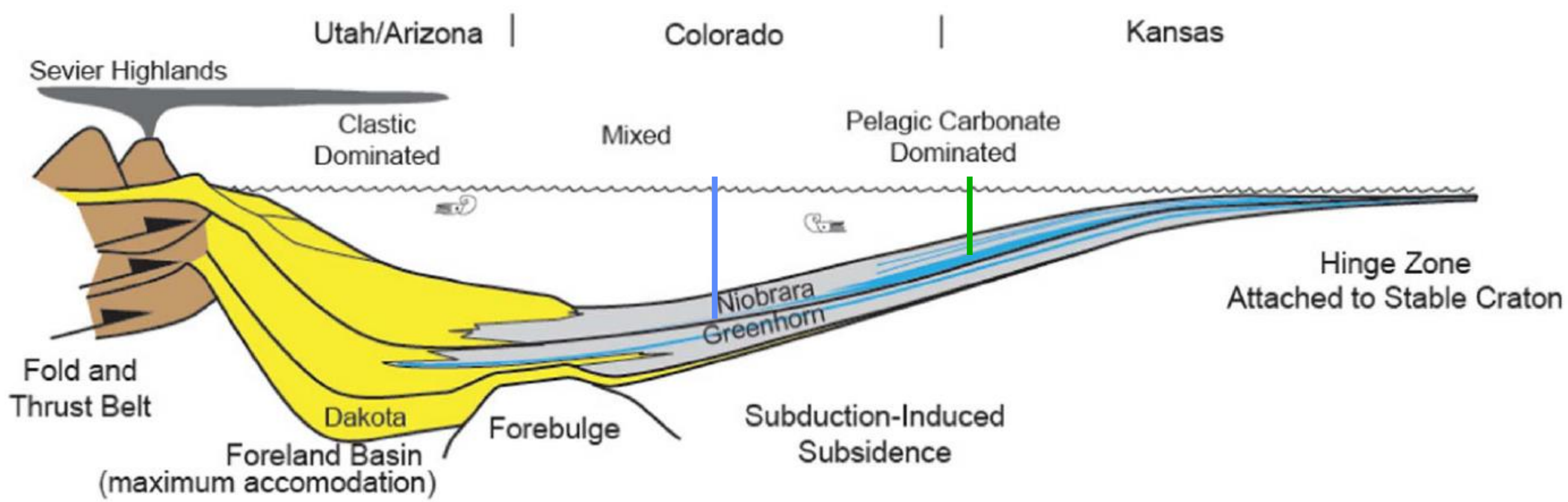
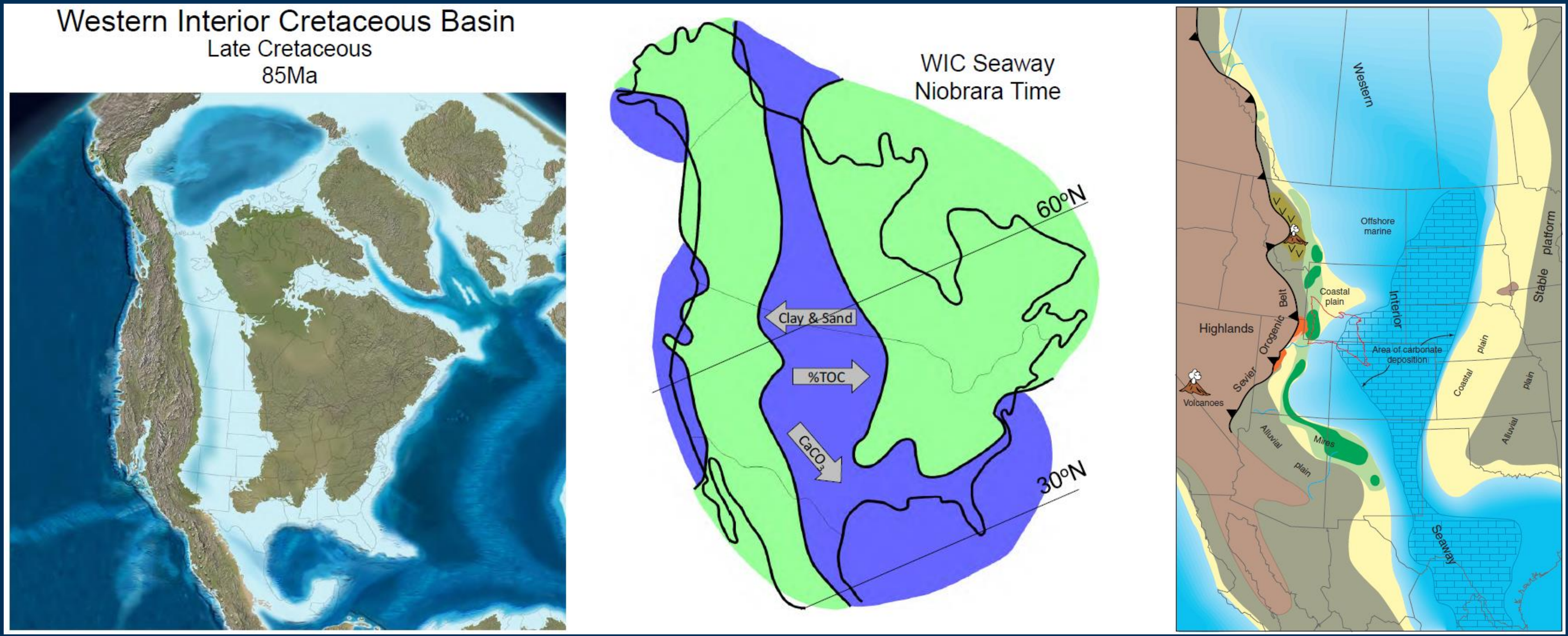


Fig. 2. Idealized *E*–W cross section showing dominant sediment types and water depth trends with in the Western Interior Sea. Modified from Kauffman (1984).

East-west cross section showing the Nobrara Formation across the display area. From Lowery et al. (2018). Colored lines show approximate locations of the Portland 1 and Rebecca Bounds cores.

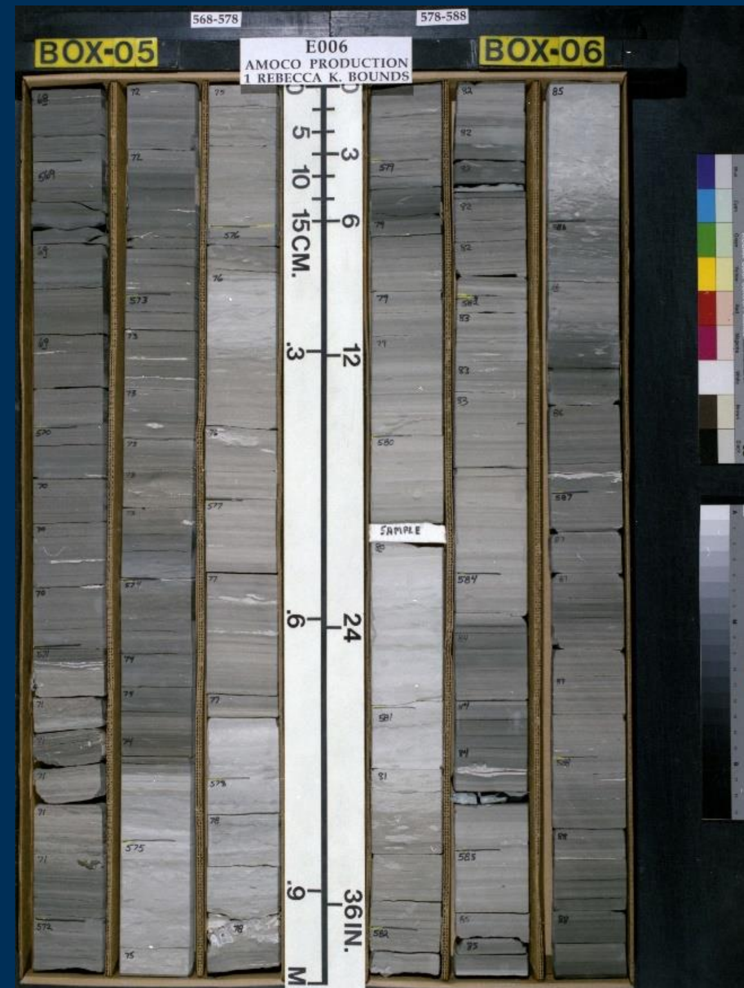
Coniacian-Campanian Paleogeography



from Blakey, 2013
www.cpgeosystems.com

Paleogeographic reconstruction of the Western Interior Seaway during Coniacian-Santonian time (left, 85 Ma) including regional depositional trends (center and right). Modified from Blakey (2011), Longman et al. (1998) by S. Sonnenberg, and Roberts and Kirschbaum, 1995.

Core Photos



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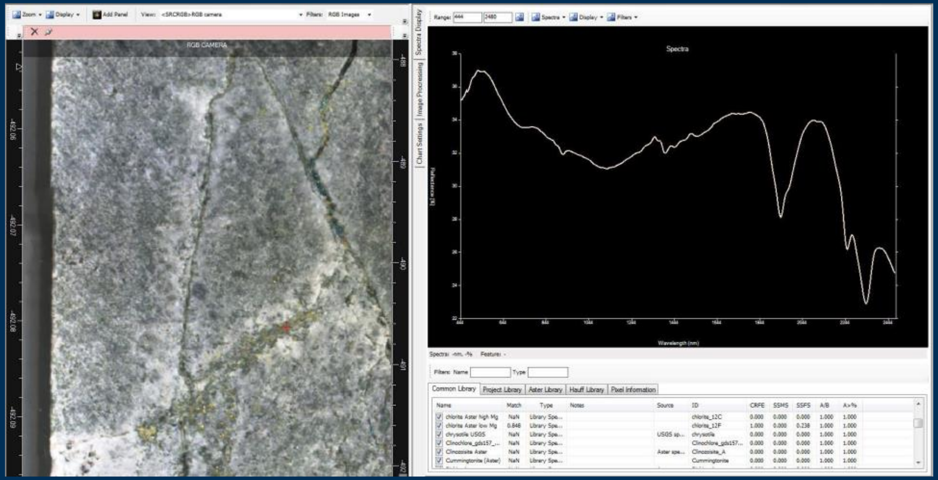
USGS 1-Portland core (left); Amoco Prod. 1-Rebecca K. Bounds core (right)
Available from the USGS Core Research Center (https://my.usgs.gov/crcwc/)

Hyperspectral Core Analysis

HSI method information
Digital photography – 50 µm resolution
3D Laser profiler – 15 µm resolution (vertical only)

Hyperspectral imagery – 500 µm resolution
Collected from 450-2500 nm (NIR-SWIR range)
3.5 nm FWHM (510 channels)
Acquires ~60,000 pix/ft of core at 2000:1 SNR

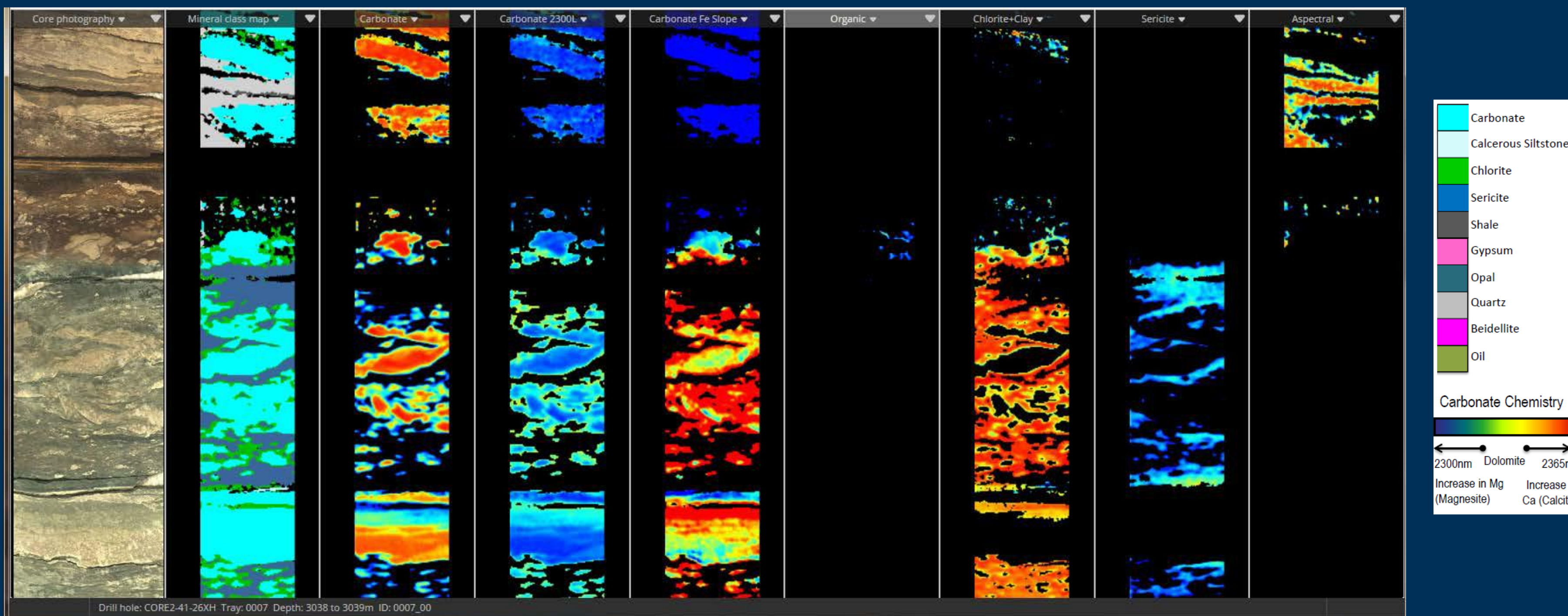
Configurable box dimensions up to ~5 ft core row length
Scan rate between ~1,300 and 1,600 ft/day



Disclaimer: Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Hyperspectral Core Analysis

RGB Photos | Mineral class map | Carbonate abundance and chemistry | Organic (oil) | Chlorite abundance | Sericite abundance | Quartz abundance



USGS

Disclaimer: Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Hyperspectral Results – Minerals and Lithologies

Mineral Name	RGB Code	Colour
Aspectral	128,0,0	
Calcite	0,255,255	
Iron-rich-Carbonate	52,82,52	
Dolomite	0,219,214	
Chlorite	0,192,0	
Clay	105,105,255	
Gypsum	213.87,171	
Hydrocarbon	255,0,0	
Iron Oxide	151,71,0	
Kaolinite	191,183,143	
Montmorillonite	175,175,255	
Quartz	0,176,240	
Sulphides	200,100,0	
Szomolnokite	255,192,0	

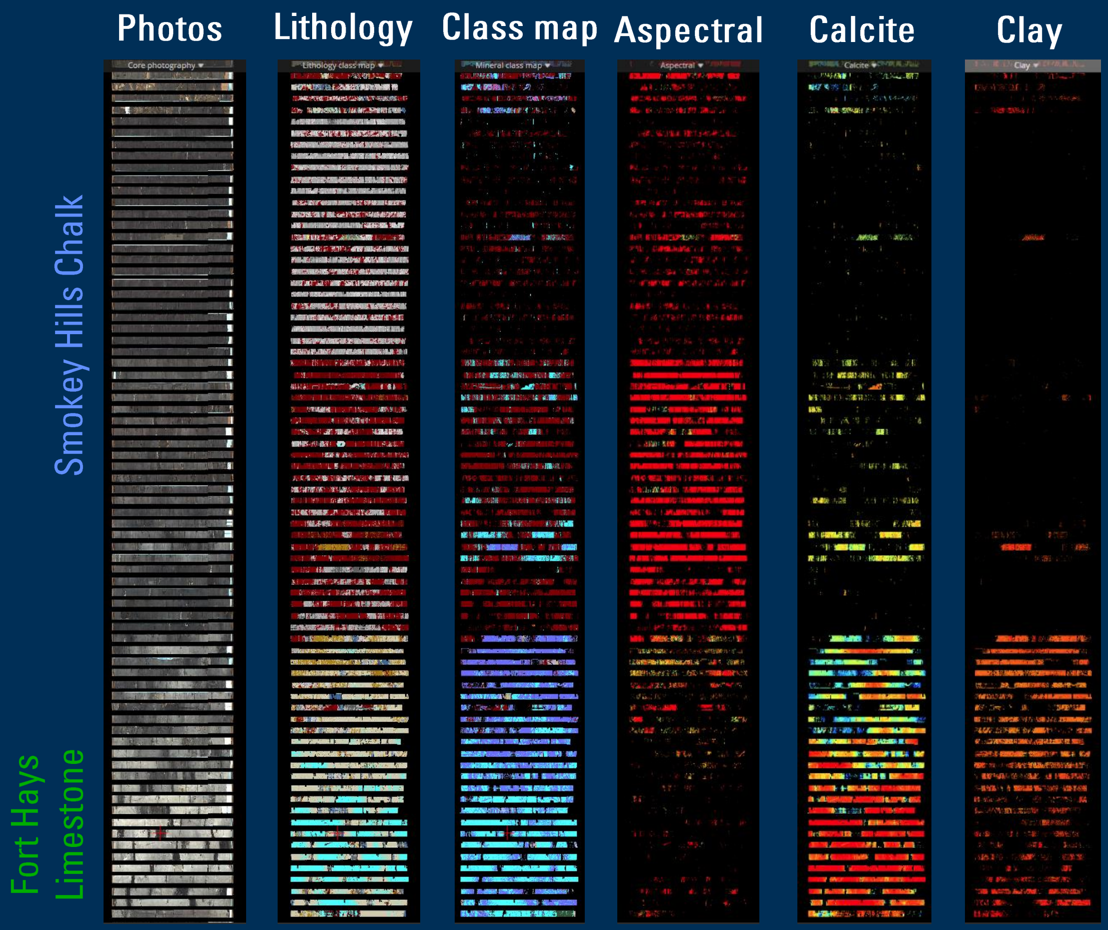
Mineral Name	RGB Code	Colour
Calcareous Sediment	0,255,255	
Calcareous Clay-rich Sediment	209,203,175	
Dark Clay-rich Sediment	31,76,171	
Bright Clay-rich Sediment	58,102,156	
Coarse Sediment	128,0,0	
Coarse Calcareous Sediment	88,0,0	
Coarse Calcareous Clay-rich Sediment	168,128,0	
Coarse Clay-rich Sediment	255,237,105	
Bright Greyish Sediment	209,209,209	
Dark Greyish Sediment	166,166,166	
Dark Sediment	95,95,95	
Evaporites	213,87,171	

14 mineral and 12 lithology classes

Hyperspectral analysis – Portland results

Mineral Class Map Colour

Mineral Name	RGB Code	Colour
Aspectral	128,0,0	
Calcite	0,255,255	
Iron-rich-Carbonate	52,82,52	
Chlorite	0,192,0	
Dickite	148,138,84	
Gypsum	213.87,171	
Illite/White Mica	58,102,156	
Iron Oxide	151,71,0	
Kaolinite	191,183,143	
Montmorillonite	175,175,255	
Quartz	0,176,240	
Sulphides	200,100,0	



Unclassified pixels are shown in black and indicate areas of low reflectance (<5%)

Aspectral pixels are distinguished by the absence of absorption features and a negative slope between 750 nm and 2450 nm. It is generally associated with siliciclastic minerals.

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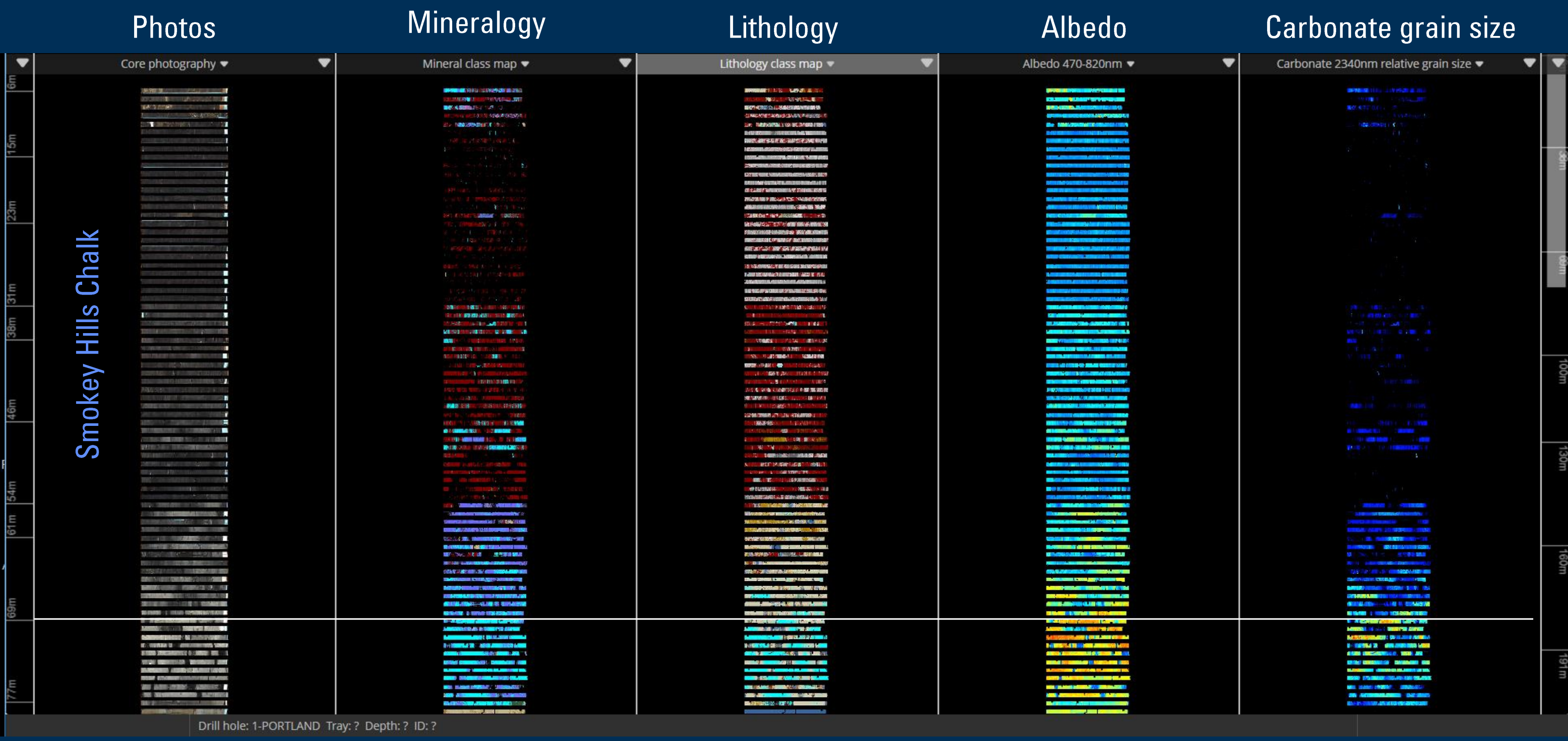
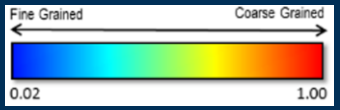
Hyperspectral Results – 1 Portland Core



Fort Hays Limestone

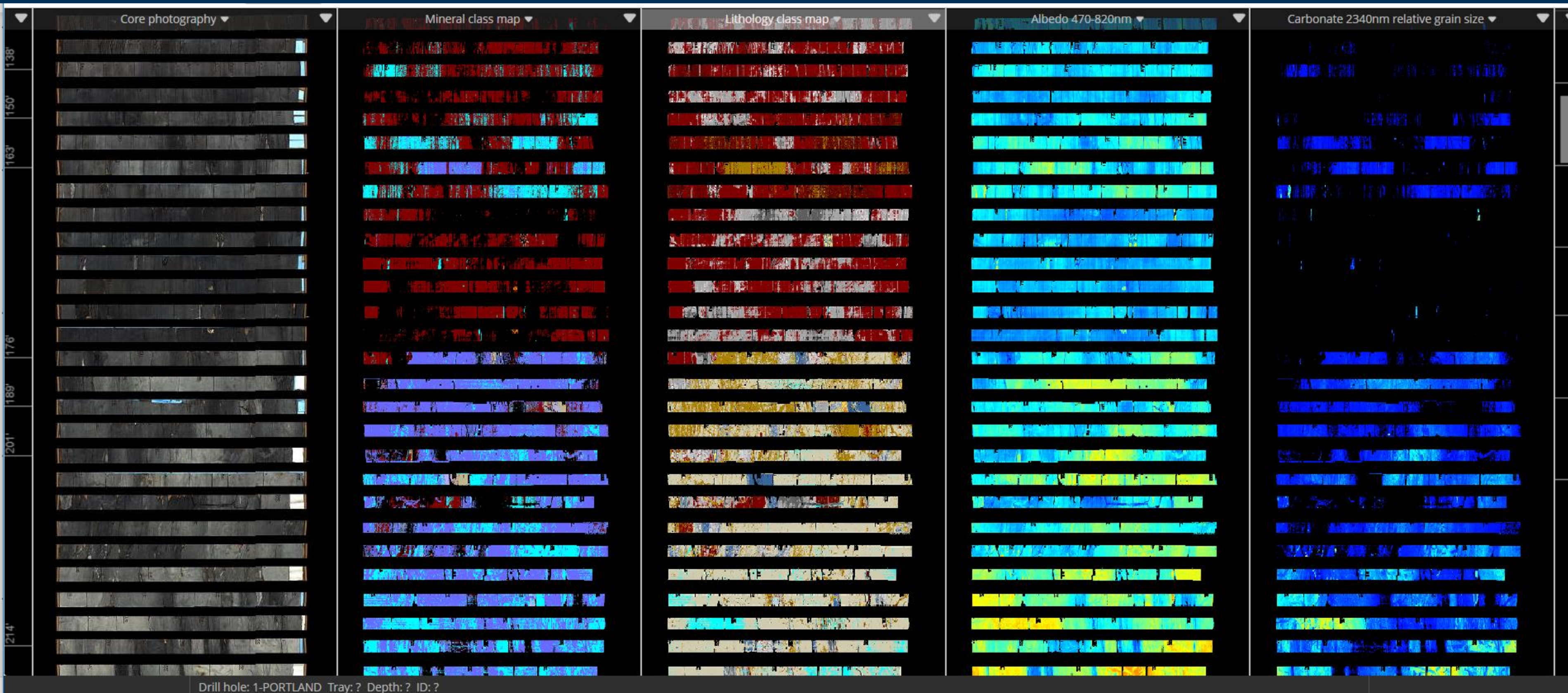
Calcite
Aspectral
Clay
Sulfides
Kaolinite

Calcareous
Coarse
Calcareous, Clay-rich
Dark
Bright Clay-rich



Hyperspectral Results – 1 Portland Core

134 ft | Photos | Mineralogy | Lithology | Albedo | Carbonate grain size



214 ft

Calcite
Aspectral
Clay
Sulfides
Kaolinite

Calcareous
Coarse
Calcareous, Clay-rich
Dark
Bright Clay-rich

Smokey Hills Chalk

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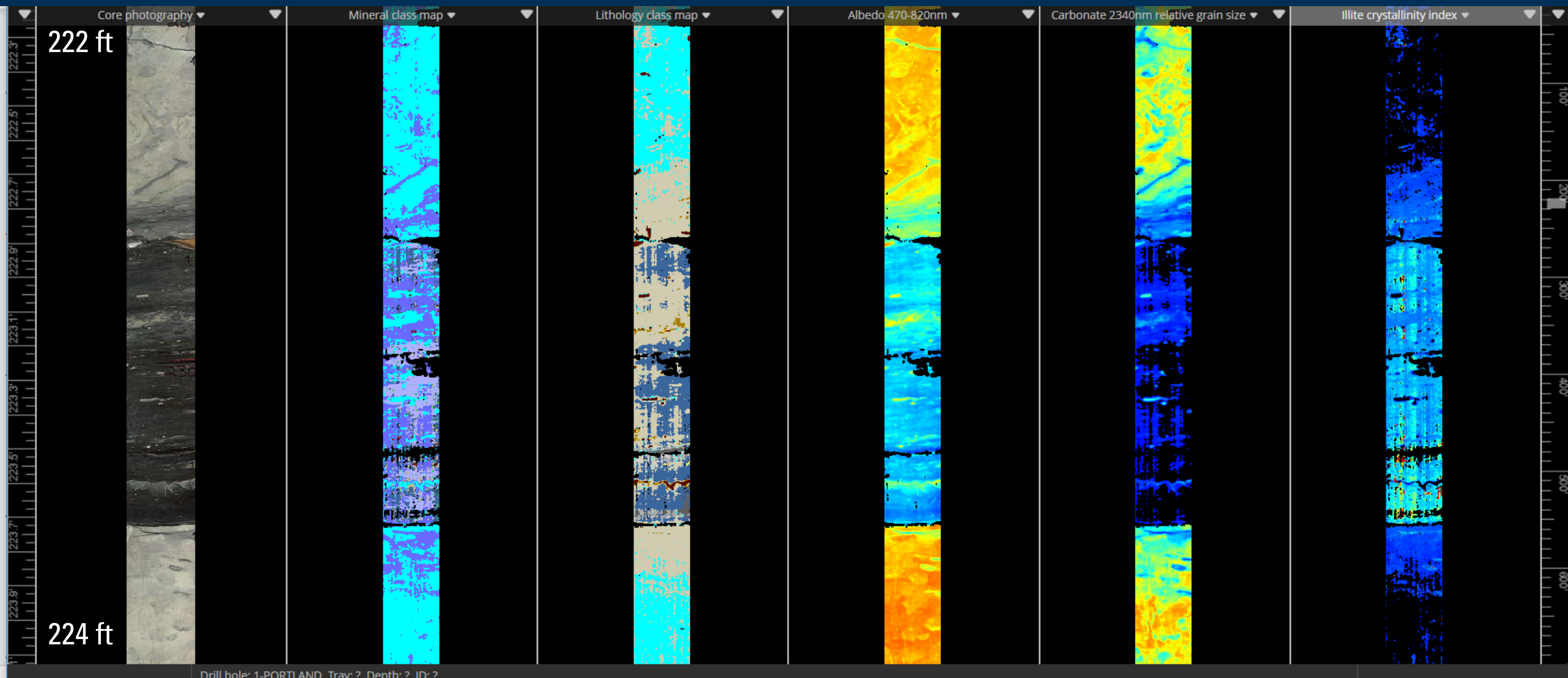
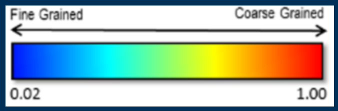
Hyperspectral Results – 1 Portland Core

Photos | Mineralogy | Lithology | Albedo | Carbonate grain size | Illite Crystallinity



Calcite
Aspectral
Clay

Calcareous
Coarse Calcareous Clay-rich
Calcareous, Clay-rich
Dark
Bright Clay-rich



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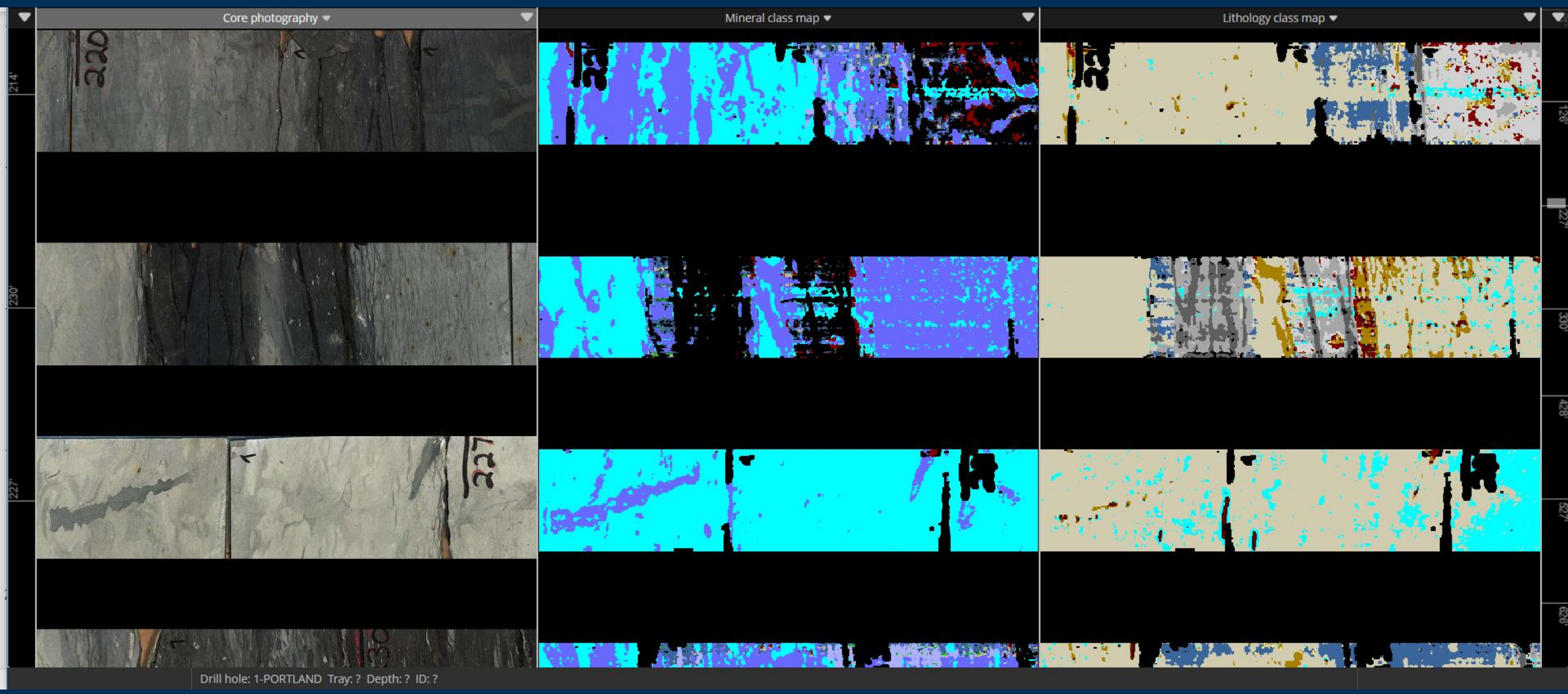
Hyperspectral Results – 1 Portland Core

Photos

Mineralogy

Lithology



Calcite
Aspectral
Clay

Calcareous
Coarse Calcareous Clay-rich
Calcareous, Clay-rich
Dark
Bright Clay-rich

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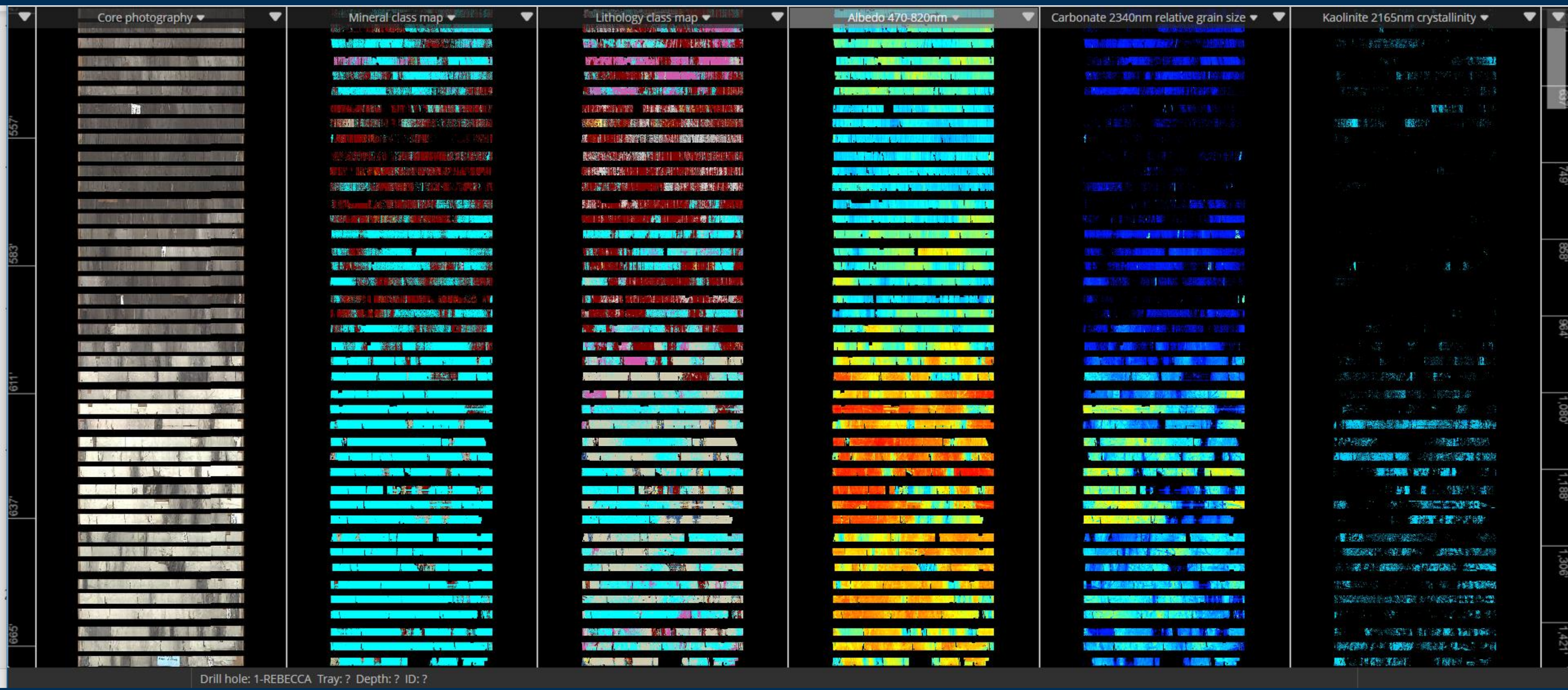
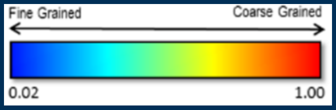
Hyperspectral Results –Rebecca Bounds Core

Photos | Mineralogy | Lithology | Albedo | Carb. grain size | Kaolinite Crystallinity



Calcite
Aspectral
Gypsum
Sulfides
Kaolinite

Calcareous
Coarse
Calcareous, Clay-rich
Evaporites
Coarse Clay-rich



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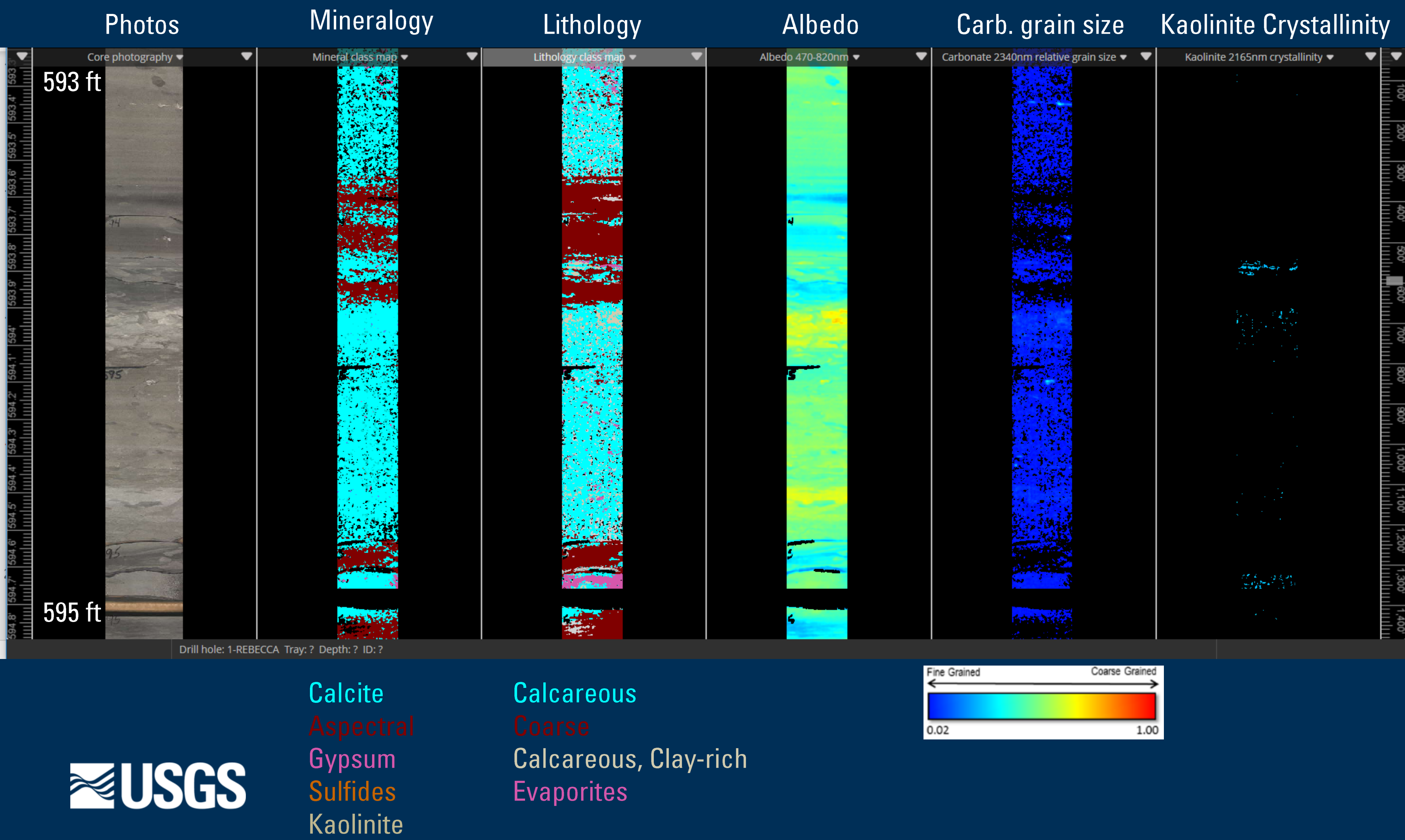
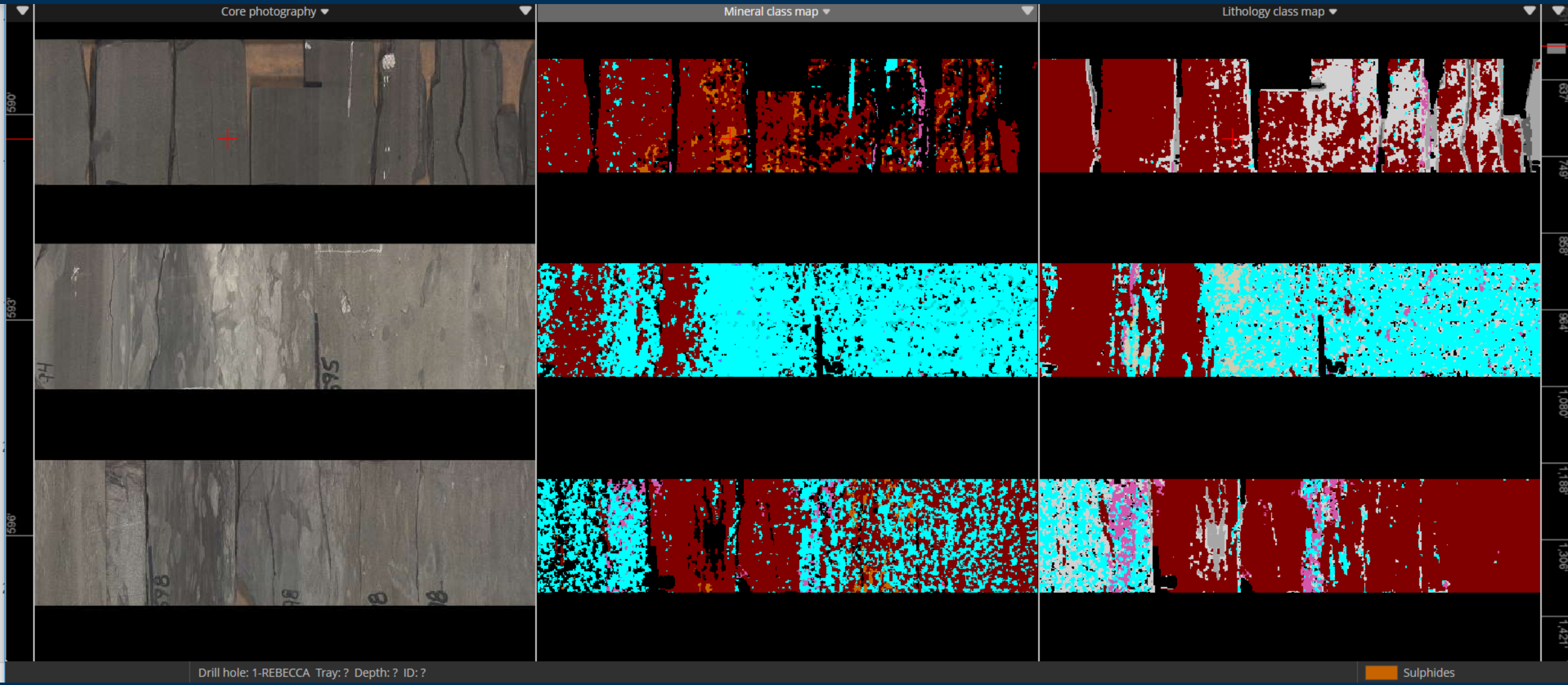
Hyperspectral Results –Rebecca Bounds Core



USGS

Hyperspectral Results –Rebecca Bounds Core

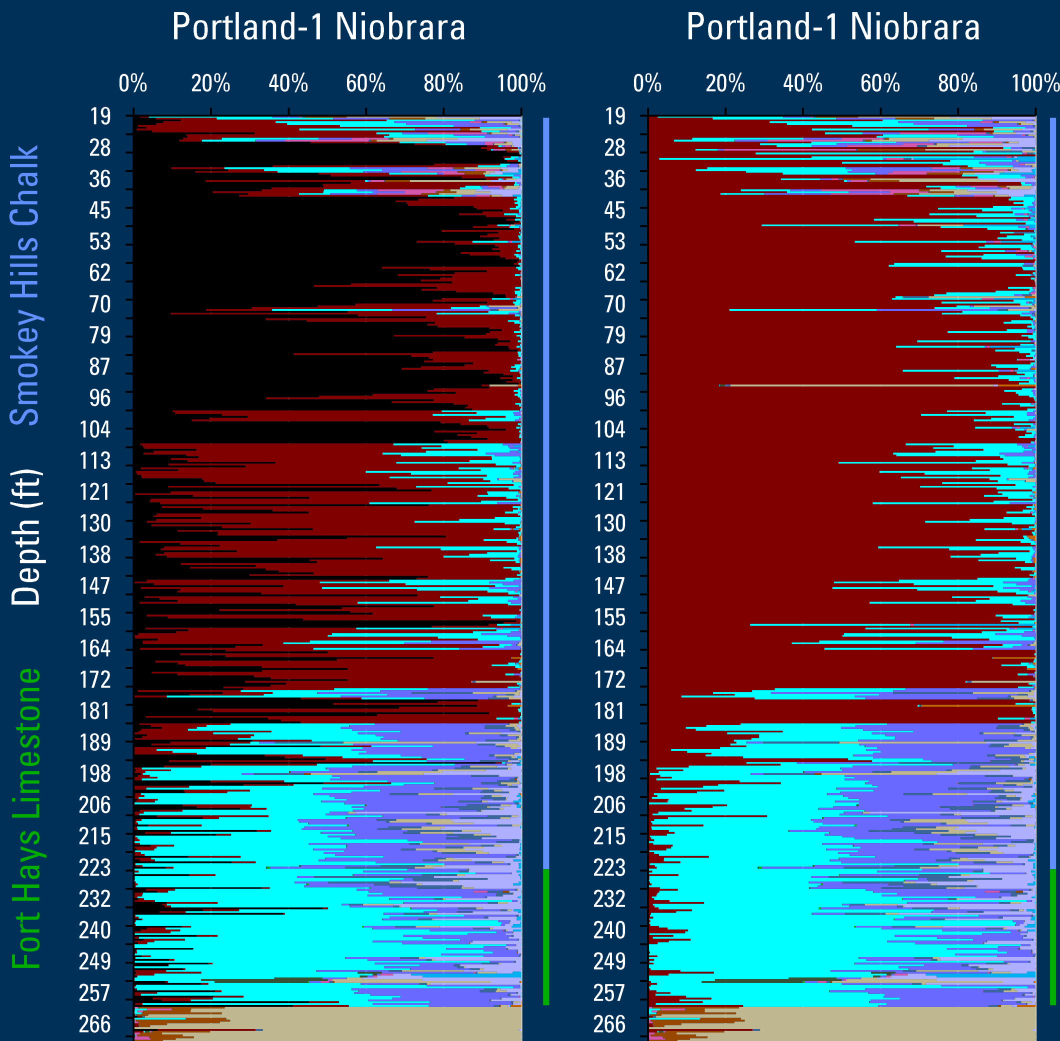
Photos | Mineralogy | Lithology



Calcite
Aspectral
Gypsum
Sulfides
Kaolinite

Calcareous
Coarse
Calcareous, Clay-rich
Evaporites

Hyperspectral Logs – 1 Portland Core



Mineral Name	RGB Code	Colour
Aspectral	128,0,0	
Calcite	0,255,255	
Iron-rich-Carbonate	52,82,52	
Chlorite	0,192,0	
Dickite	148,138,84	
Gypsum	213.87,171	
Illite/White Mica	58,102,156	
Iron Oxide	151,71,0	
Kaolinite	191,183,143	
Montmorillonite	175,175,255	
Quartz	0,176,240	
Sulphides	200,100,0	

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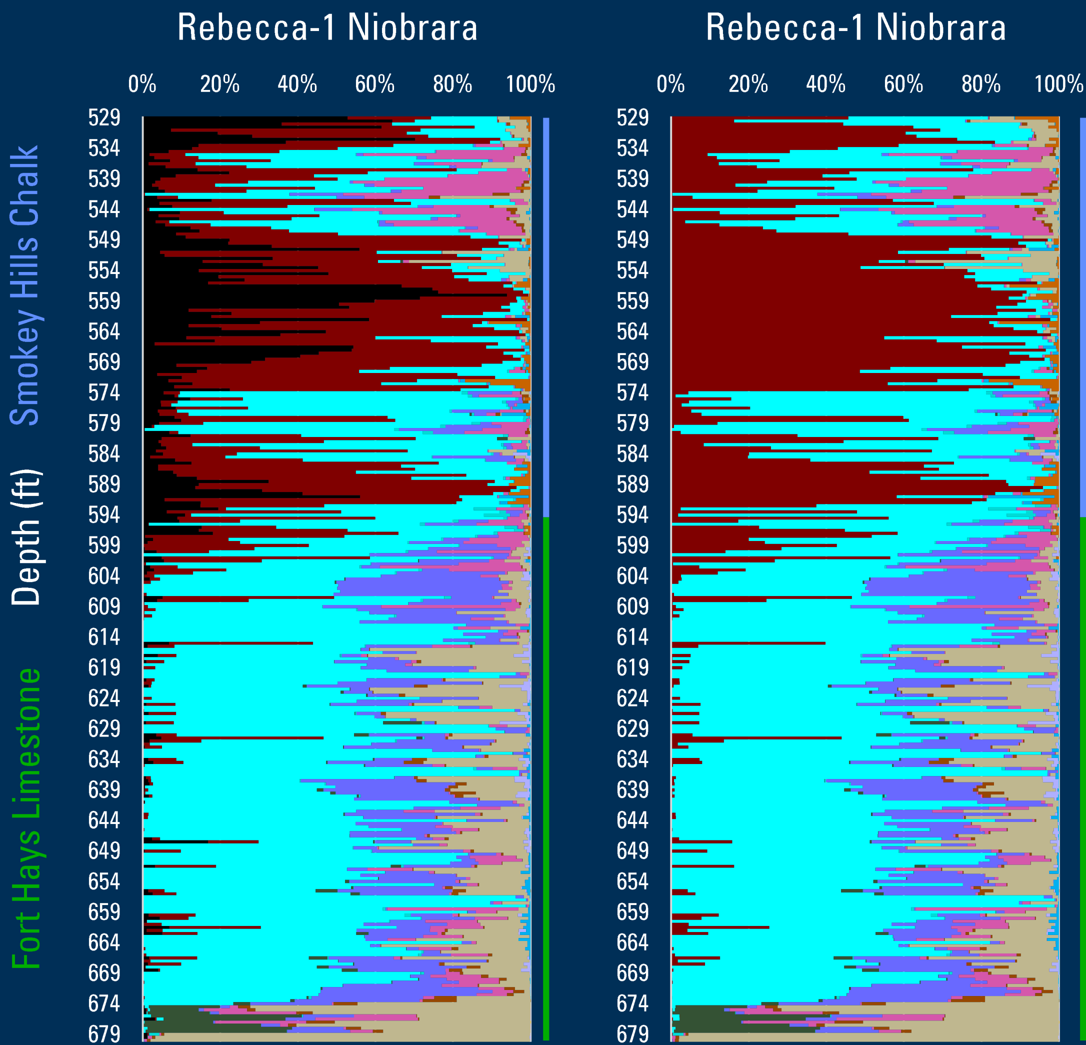
Upscaling data from 0.5 mm pixels to 0.1 or 0.5 ft resolution logs provides a useful overview and summary of the data.

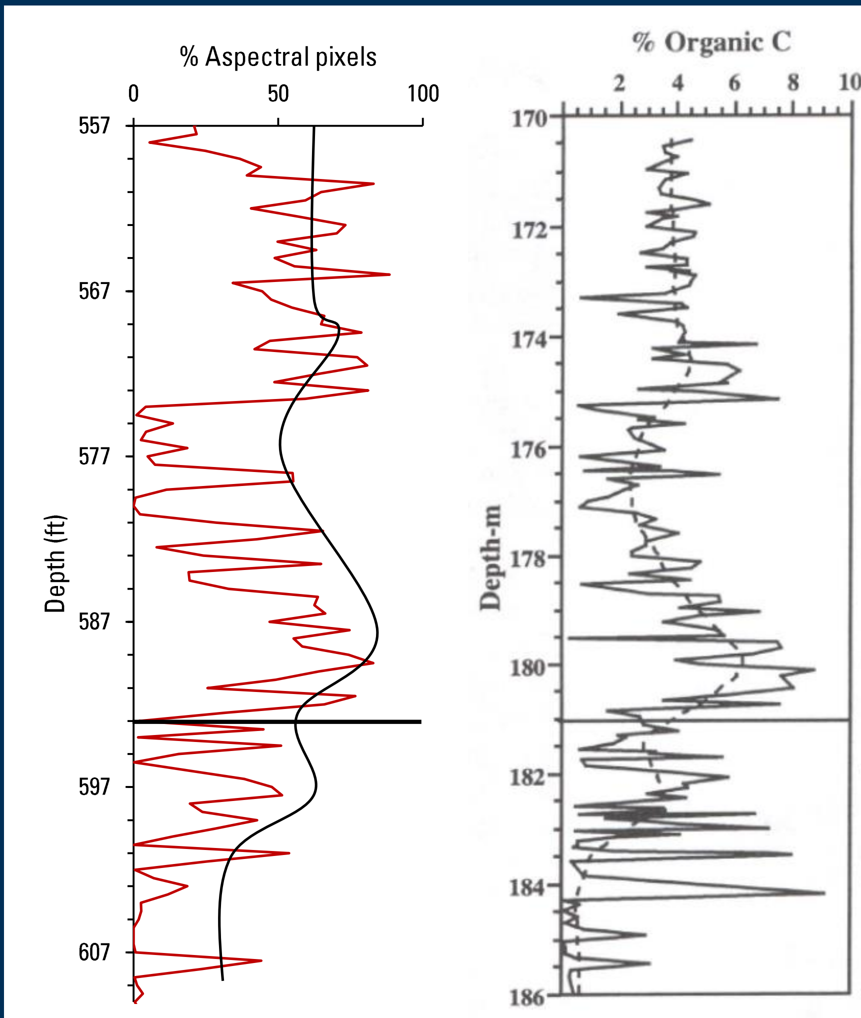
Hyperspectral Logs – Rebecca Bounds Core

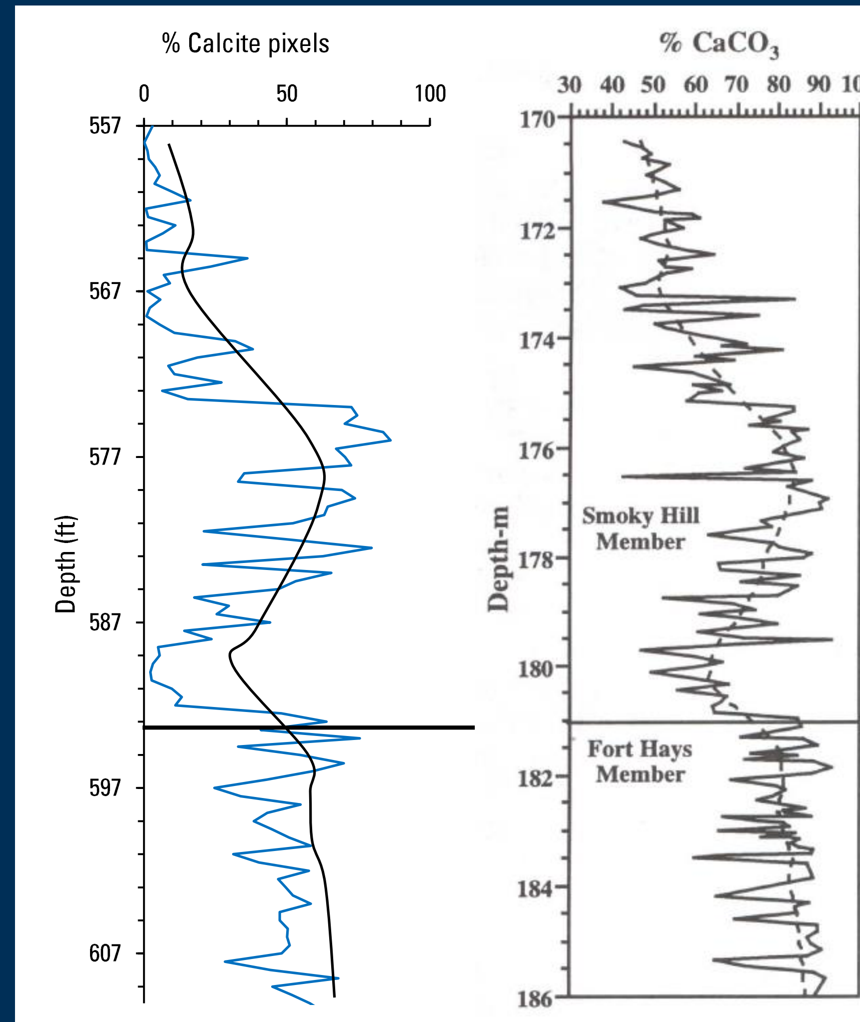


Mineral Name	RGB Code	Colour
Aspectral	128,0,0	(dark red)
Calcite	0,255,255	(cyan)
Iron-rich-Carbonate	52,82,52	(dark green)
Dolomite	0,219,214	(turquoise)
Chlorite	0,192,0	(green)
Clay	105,105,255	(blue-violet)
Gypsum	213.87,171	(pink)
Hydrocarbon	255,0,0	(red)
Iron Oxide	151,71,0	(brown)
Kaolinite	191,183,143	(tan)
Montmorillonite	175,175,255	(lavender)
Quartz	0,176,240	(sky blue)
Sulphides	200,100,0	(orange)
Szomolnokite	255,192,0	(yellow)

These data can also be compared to other bulk or lower resolution data.

Comparison of Hyperspectral and Geochem Logs

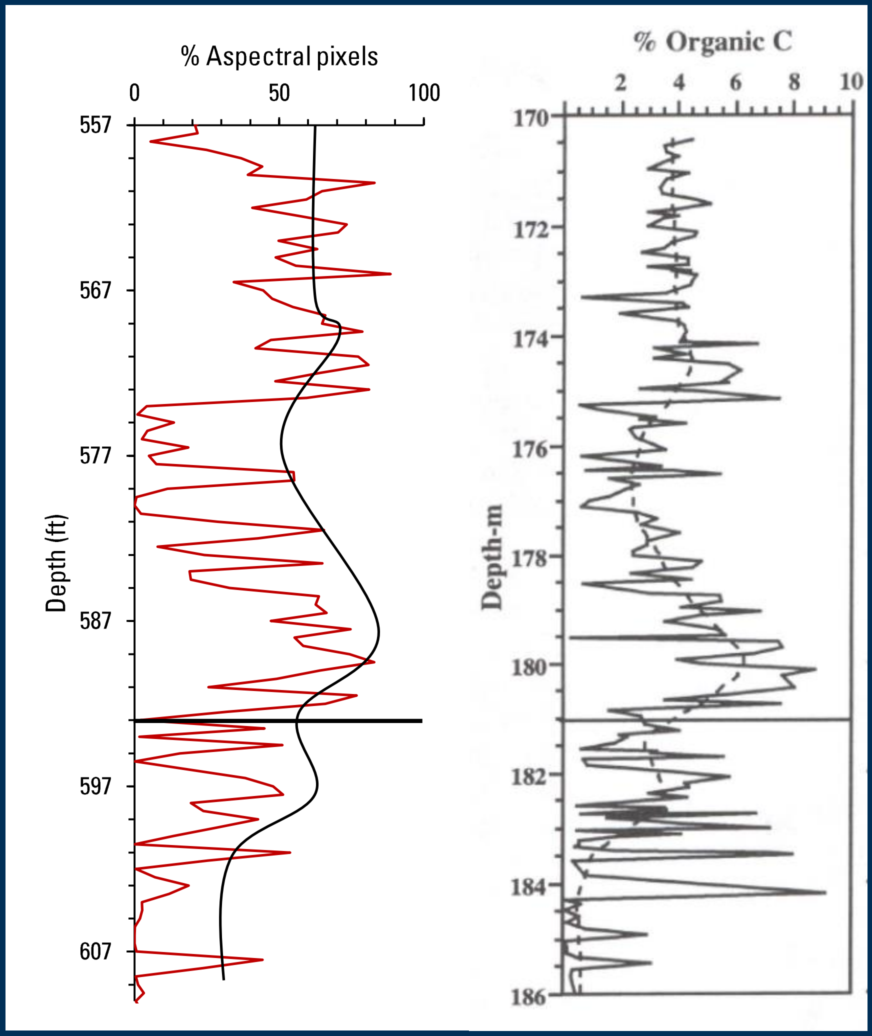


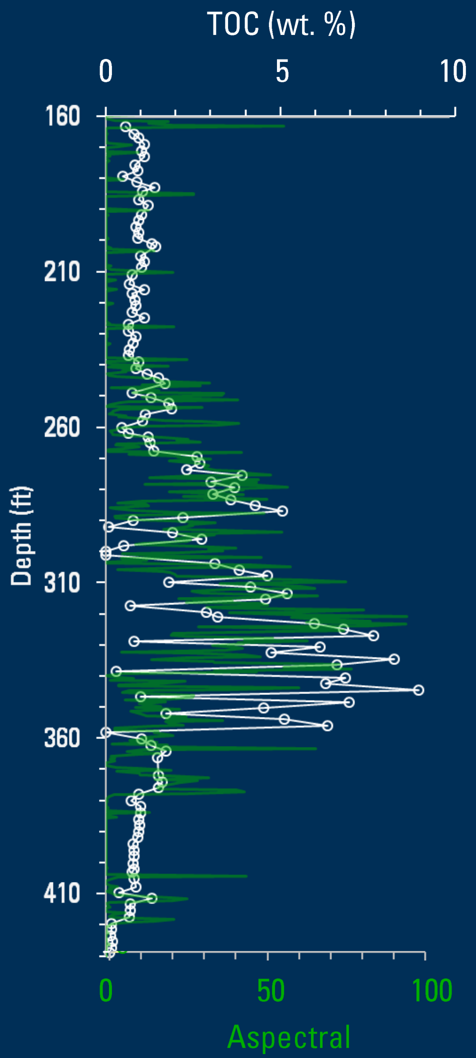


In general, the hyperspectral logs show good agreement with available geochemistry data.

Rebecca Bounds Geochemistry results (Dean and Arthur, 1998).

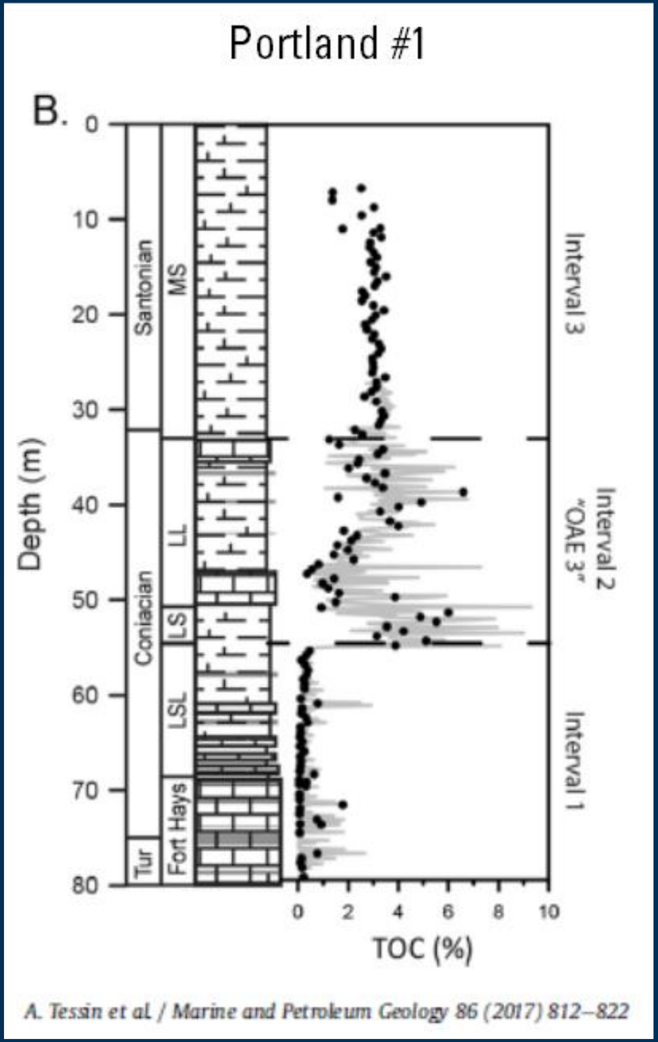
Geochemistry and Log Data

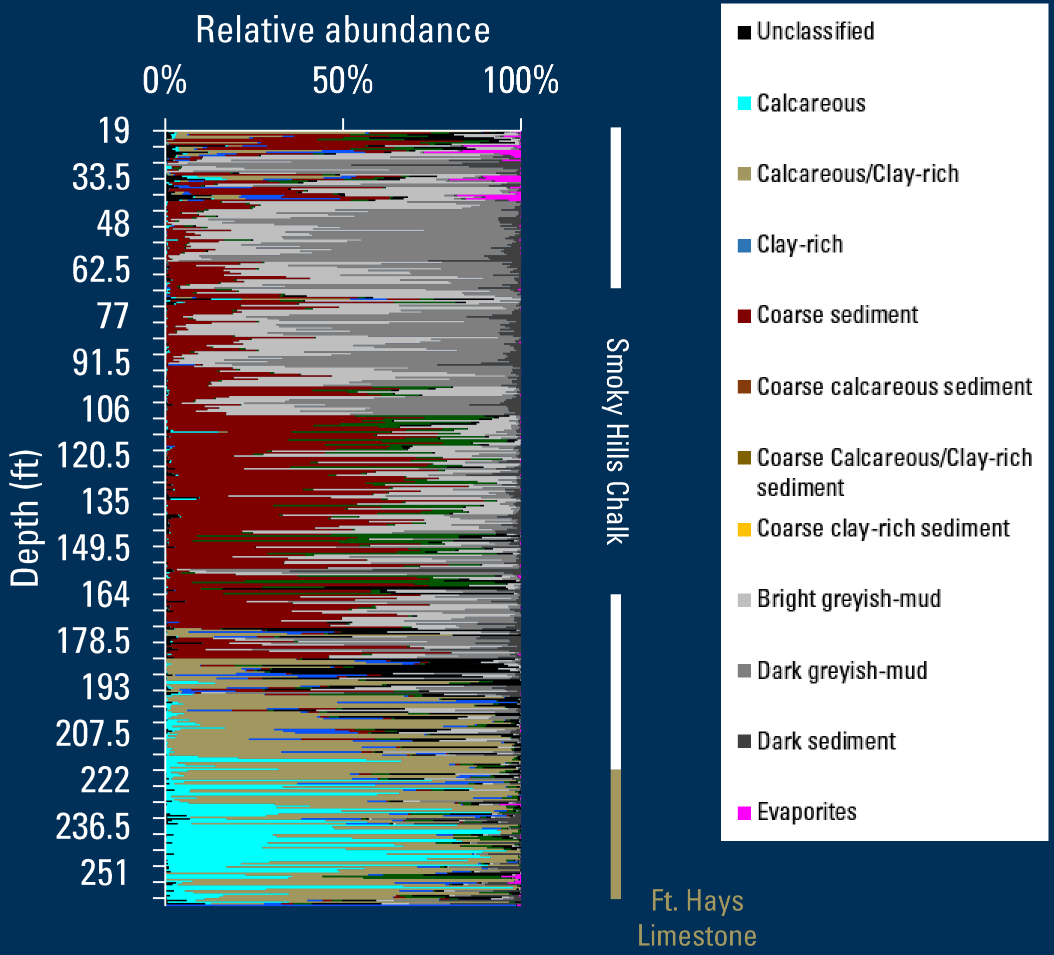




Left: Comparison of Rebecca Bounds TOC (Dean and Arthur, 1998) and Aspectral pixel percentage.
Right: Comparison of Eagle Ford TOC (USGS GC-1 core) and Aspectral pixel percentage.

Hyperspectral Logs



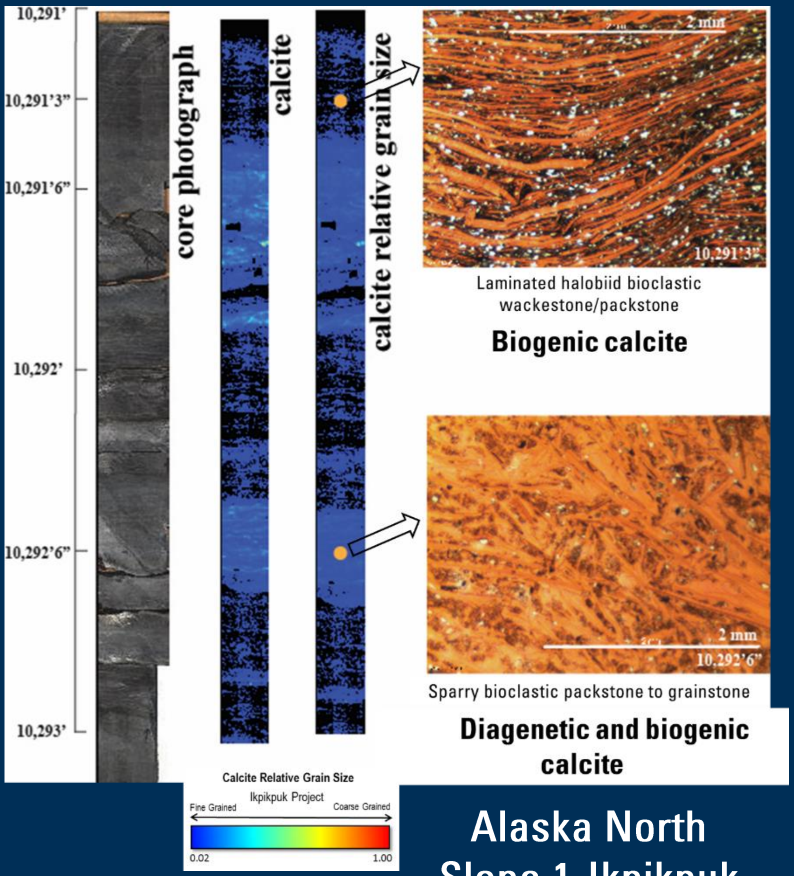


Lithology (from 0.5 ft averaged logs)

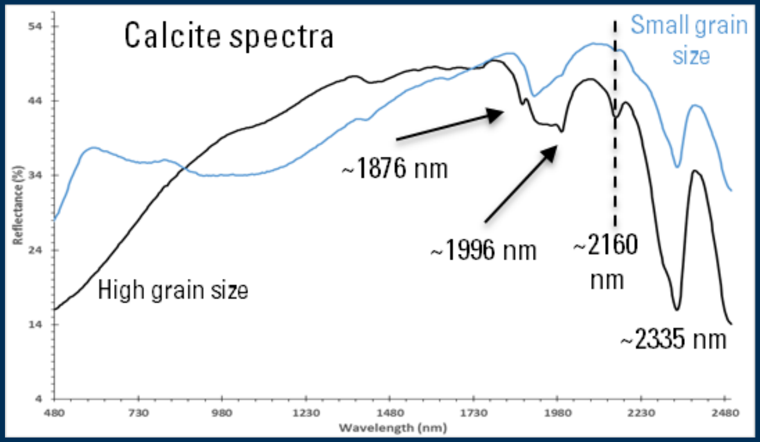
USGS

High resolution lithology logs may be useful for understanding cyclic patterns in shale systems.

Comparison of Hyperspectral and Thin Section Microanalyses



Alaska North Slope 1-Ikpikpuk



Core photos, hyperspectral imaging results (calcite mineral match and relative grain size), and thin sections from Ikpikpuk-1.

Relative grain size is derived from calcite spectral features

Recent publications by Baissa et al. (2011) and Zaini et al. (2012) have shown a relationship between the deepening of the main calcite feature around 2330 nm and increasing calcite grain size.

The depth of the 2330 nm calcite-related feature was extracted and normalized by the maximum depth giving a relative grain size proxy.

USGS

Summary

High-resolution (0.5 mm) hyperspectral data on several Niobrara cores provides a digital archive of this formation.

These data will eventually be available through the USGS Core Research Center in Denver, CO. Web access is the preferred way to do this, but IT limitations may make on-site access the only practical solution.

One goal of this project is that this data be applied to problems related to understanding source rock and other mudrock properties at a scale and resolution not available with other bulk and microscopic methods.

If you're interested in collaborating on ways to use these datasets, please contact me at: jbirdwell@usgs.gov

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QUESTIONS?