Application of Hyperspectral Core Logging for Coal Mineral Characterisation in CSG Reservoirs*

Natalya Taylor[1], Frank Honey[2], Ronell Carey[2], Rodney Borrego[3], Sandra Rodrigues[1], and Joan Esterle[1]

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[1]School of Earth Sciences, The University of Queensland, St Lucia, QLD, Australia (j.esterle@uq.edu.au)
[2]Corescan Pty Ltd., Perth, WA
[3]School of Geography, Planning, Environment and Mgmt, University of Queensland, St Lucia, QLD, Australia

Abstract

The occurrence of mineral matter in coal matrix and cleat networks can have a deleterious effect on coal seam gas reservoirs through reduction in gas holding capacity, blocking permeability pathways, reactivity with drilling fluids and potentially the generation of fines. Mineral matter in coal is commonly characterised by geochemical analyses, such as XRD, XRF, or petrology and more recently CT scanning, and this requires sampling. Sampling requires time, is not always contiguous, and destructive tests can lose the association with the host coal and strata lithology. Core scanners have become more common, and we trialed the application of Corescan™ hyperspectral core scan technology to characterise Late Permian coals from the Bowen Basin. Hyperspectral loggers can provide information on the mineralogy of coal and interburden using visible and near (VNIR), short wave (SWIR) and thermal (TIR) infrared wavelengths. Corescan™ currently operates in VNIR and SWIR from 450 to 2500nm. Corescan™ can perform profile and 30mm swath scans at 0.5mm intervals to produce high-resolution mineral maps.

Five Late Permian coal cores from the Bowen Basin, Australia were selected for their variability in rank and mineral matter occurrence. Cores ranged in rank from a maximum vitrinite reflectance (Rvmax) of 1.2 to 2.2% (Core 1=1.2; Core 2=1.8; Core 3=2.2; Core 4=2.0; Core 5=1.7). The data were processed to the Coreshed™ facility, which provides a virtual warehouse facility to securely store core data. Coreshed™ provided a laser core profile, true and false colour spectral images, core photography, mineral class map, mineral abundance/purity maps for each mineral identified, organic matter abundance/purity map and three organic slope maps for each core.

Corescan™ effectively detected carbonates and clay minerals in coal cores, occurring both as bands or lenses and in the cleat system. It did not detect quartz and feldspar spectra that require TIR (Li et al 2007), nor trace minerals such as rutile, pyrite and apatite with grain size smaller than the 0.5mm map pixel resolution. The mineral content was confirmed by petrography and XRD analysis and compared to previous results obtained from QEMSCAN (Rodrigues et al 2013), and were consistent with a common Bowen Basin mineralogy (Permana

et al 2013; Uysal et al 2000). Carbonates (in this case siderite and calcite) were common in bands whereas the cleat mineralisation commonly presented as Dickite or Kaolinite. Dickite would suggest some degree of hydrothermal alteration being responsible for cleat infill.

In addition to identifying mineral matter, the Corescan™ produced a spectral organic abundance and organic slope maps using different peaks (1300/600; 2100/600 and 2100/1300). By visual comparison to the photos and logged core, variations were interpreted to reflect the different lithotypes, such as vitrain (bright bands) and durain (dull bands). To test this, an ASD Field Spectrometer of range 350-2500nm and two 70W quartz- tungsten- halogen lamps and were used to measure the spectral reflectance of end member lithotypes from all cores (ASDI 2014). The ASD was optimized, set to a 5mm spot size and calibrated with a spectralon standard. ASD spectral data were processed in Microsoft Excel™ and imported into Exelis ENVI™ spectral image processing software to create spectral libraries by lithotype means overall and within each core (Exelis 2013).

The spectral organic abundance and organic slope maps partially correlated with coal lithotypes and with thermal maturity. Organic matter displayed a consistent spectral pattern across wavelengths for mean lithotype data with vitrains at higher spectral reflectance than durains in all cores. Although expected, it is nice to have quantitative confirmation from the tool. ASD spectral reflectances were plotted by lithotype to compare spectral slope patterns between cores. Although correspondence was not 100%, the lower ranked cores (Cores 1, 5, 2), had a lower spectral reflectance than the higher ranked cores (Cores 4, 3) for vitrain bands, but the trend was less apparent in the durain bands.

These results suggest that the technology can be improved to provide information to assist in local to regional correlation; identifying zones of deleterious clays that can reduce borehole stability or generate fines, and properties that affect reservoir behaviour of coals and interburden.

References Cited

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Permana, A.K., C.R. Ward, L. Zhongsheng, and L.W. Gurba, 2013, Distribution and origin of minerals in high-rank coals of the South Walker Creek area, Bowen Basin, Australia: International Journal of Coal Geology, v. 115-116, p. 185-207.

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Team

- **Natalya Taylor**, UQ School of Earth Sciences 3rd year student project
- Frank Honey, Corescan Pty Ltd- Perth, WA
- Ronell Carey, Corescan Pty Ltd- Perth, WA
- Rodney Borrego, UQ School of Geography, Planning, Environment & Mgmt
- Sandra Rodrigues, UQ School of Earth Sciences
- Joan Esterle, UQ School of Earth Sciences

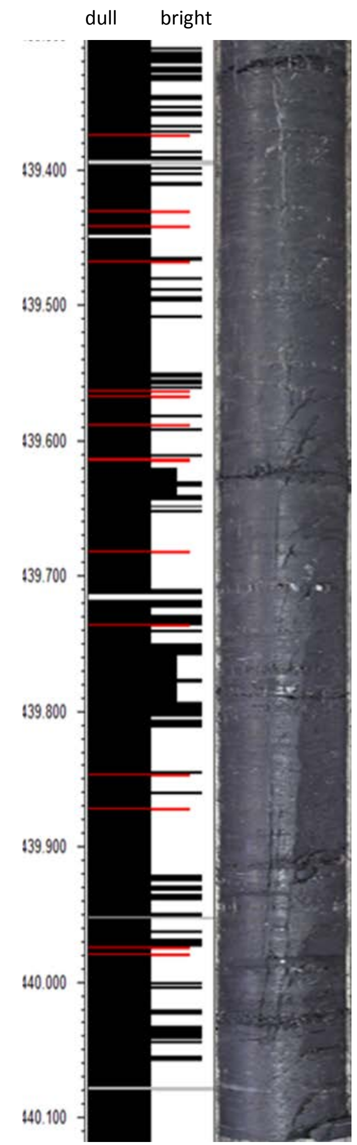
Objective- a test of the technique

- To determine mineral matter type and occurrence (as bands, lenses, cleats, fractures) in coals
- To identify coal lithotypes
- To estimate rank through core reflectivity

Outcomes if successful

- Non destructive method for coal core characterisation- grade, type and rank
- Identification of mineralised cleat and fracture systems that can reduce permeability
- Identification of clay minerals that might generate solids

Lithotype log



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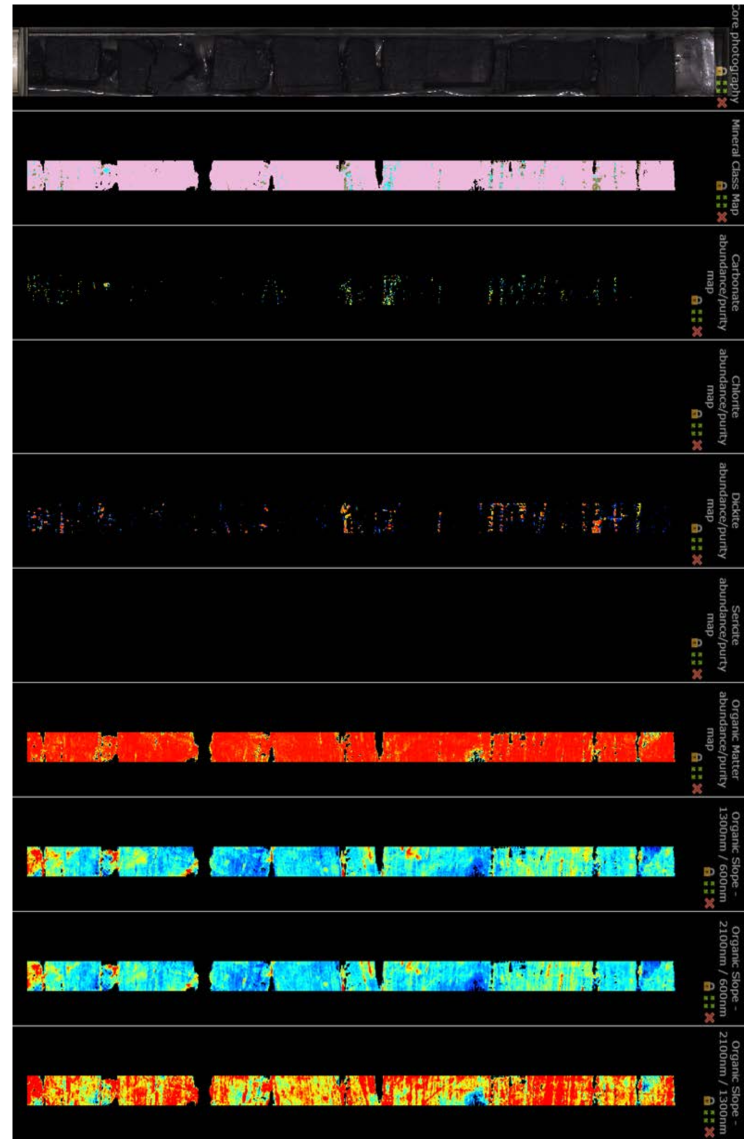
Methods

- Core scanning
  - Corescan^{TM} Hyperspectral Core Imager (HCI)
    - 0.5mm spot size on a 0.5x0.5mm grid
  - Data processing and mineral interpretation
  - Development of "organic abundance" finger prints*
- Complementary XRD for mineral interpretation
- Core logging for coal lithotype identification (mm scale)
- Petrographic analysis
  - Vitrinite reflectance for rank estimation
  - Maceral analysis for composition confirmation
- Proximate analysis
- ASD field spectrometry of lithotypes in core
  - 5.0mm spot size on end member lithotypes
    - Vitrain, durain, fusain, coked coal

Samples

- Late Permian age coal core from Bowen Basin
- Maximum vitrinite reflectance (Rvmax) of 1.2 to 2.2%
  - Five 100cm cores

Corescan^{TM} output- 1 core



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Frank Honey (Chief Scientist CORESCAN) demonstrates the Hyperspectral Core Imager to Sandra Rodrigues from the University of Queensland.
Photo: Natalya Taylor Location: CORESCAN Sumner Park, QLD

Corescan ™

Spectrometers
Visible Near Infra Red (VNIR)
Short Wave Infra Red (SWIR-A, SWIR-B)

Spectral Range: 400-2500 nm

Scan mode: 0.5mm square pixel grid over 30mm swath

HyLogger ™

Spectrometers
Visible Near Infra Red (VNIR)
Short Wave Infra Red (SWIR)
Thermal Infra Red (TIR)

Spectral Range: 400-14000 nm

Scan mode: 8mm profile scan

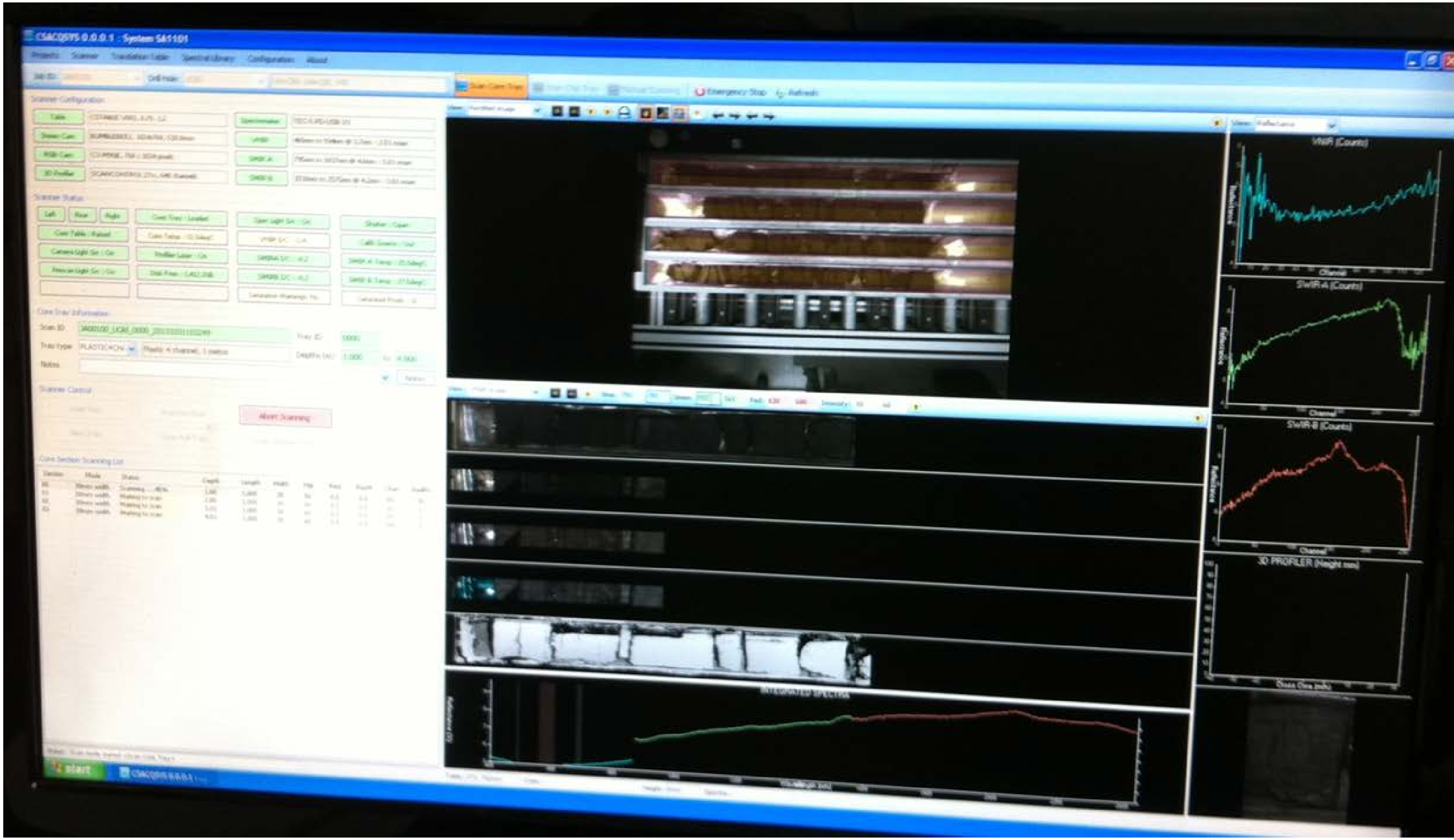
Wavelength region	Wavelength range (nm)	Mineralogy
VNIR	400 - 1100	Iron oxides and hydroxides manganese oxides, rare earths
SWIR	1100 - 2500	Hydroxyls (aluminium, manganese and iron), carbonates, sulphates, micas, amphiboles
TIR	5000 - 14 000	Carbonates, silicates, including quartz, feldspar, plagioclase, olivine, pyroxene, garnet

Complementary techniques

http://www.corescan.com.au/services/the-corescan-system

http://www.csiro.au/en/Organisation-Structure/Flagships/Minerals-Down-Under-Flagship/Exploration/hylogging-systems/HyLogging-technology.aspx

Corescan TM Data Display



Real-time digital data display during Hyperspectral Core Imaging process
Photo: Natalya Taylor
Location: CORESCAN Sumner Park, QLD

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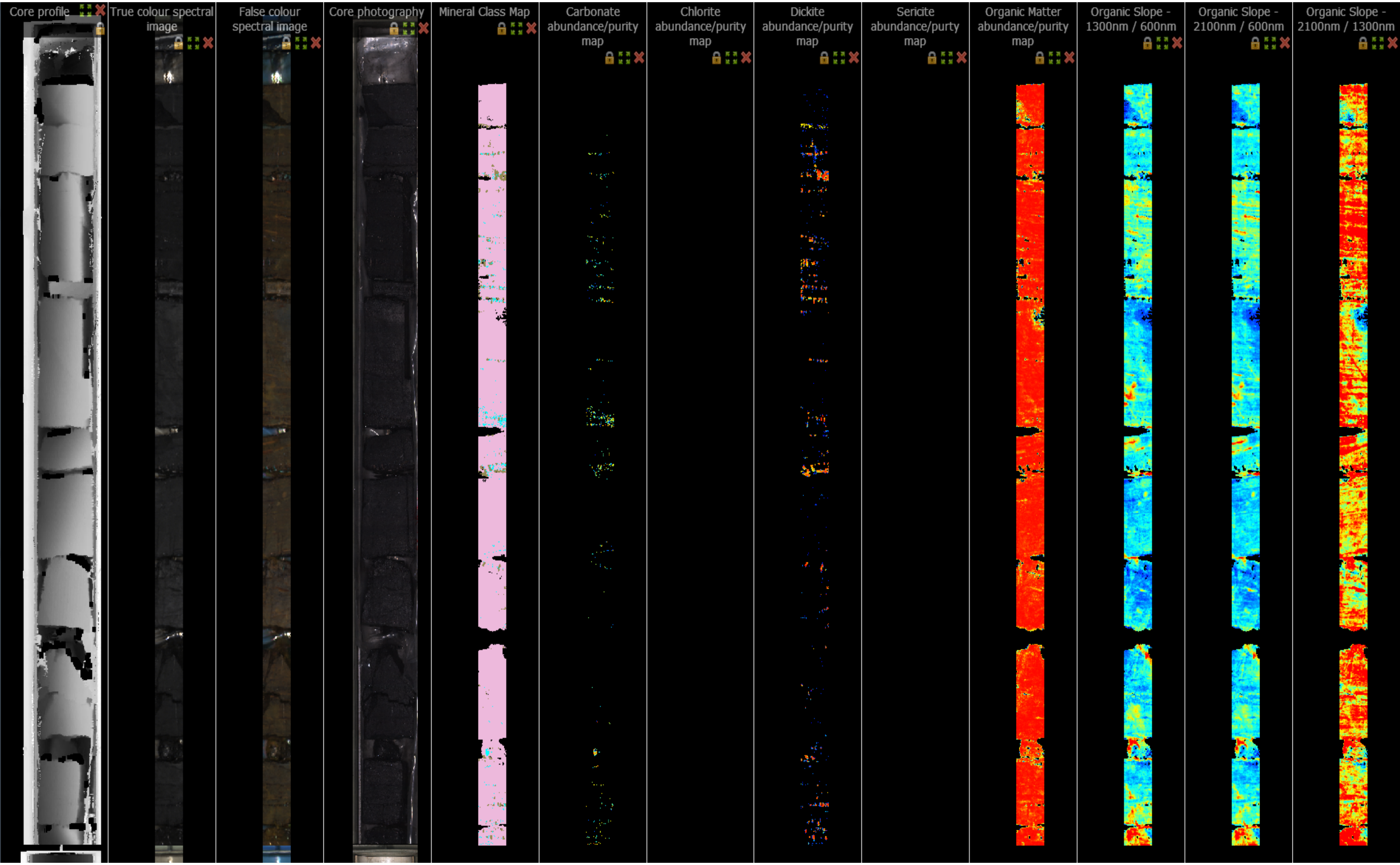
Corescan TM Output Post Processing with Mineral and Organic Interpretation



Complementary XRD Results

01 – Corescan ID chlorite
XRD Identified as chlorite

02 – Corescan ID dickite
XRD Identified as kaolinite

03 – Corescan ID sericite
XRD Identified as illite/smectite (montmorillonite)

04 – Corescan ID undetected
Identified as quartz, calcite, rectorite, chlorite, illite/smectite (montmorillonite)

Table of phase concentration estimates (nominal, wt%, absolute)

XAF8529	1	2	3	4
UQ-ES	XRD01	XRD02	XRD03	XRD04
Nondiffracting/unidentified	38.9	35.7	74.3	61.1
Quartz	15.8	17.4	4.2	10.2
Calcite		1.7		10.2
Siderite	19.9			3.5
Dolomite (feron)		37.9	1	1.2
Ankerite		3.3		
Albite		2		2.8
Chlorite (Chamosite)	16.3		0.8	3.5
Kaolinite	5.4	2.1		2.3
Mixed layer illite/smectite	3.7		19.7	5.2

Table of clay phase identifications (qualitative)

XAF8529	1	2	3	4
UQ-ES	XRD01	XRD02	XRD03	XRD04
Kaolinite	minor	abundant		minor
Chlorite (Chamosite)	major		minor	major
Mixed layer Illite/Smectite	minor	minor	abundant	major
Rectorite		minor		major

Abundant – nominally more than 40 wt%
Major – nominally greater than 10 wt% but less than 40 wt%
Minor – nominally grater than 1 wt% but less than 10 wt%
Trace – nominally less than 1 wt%

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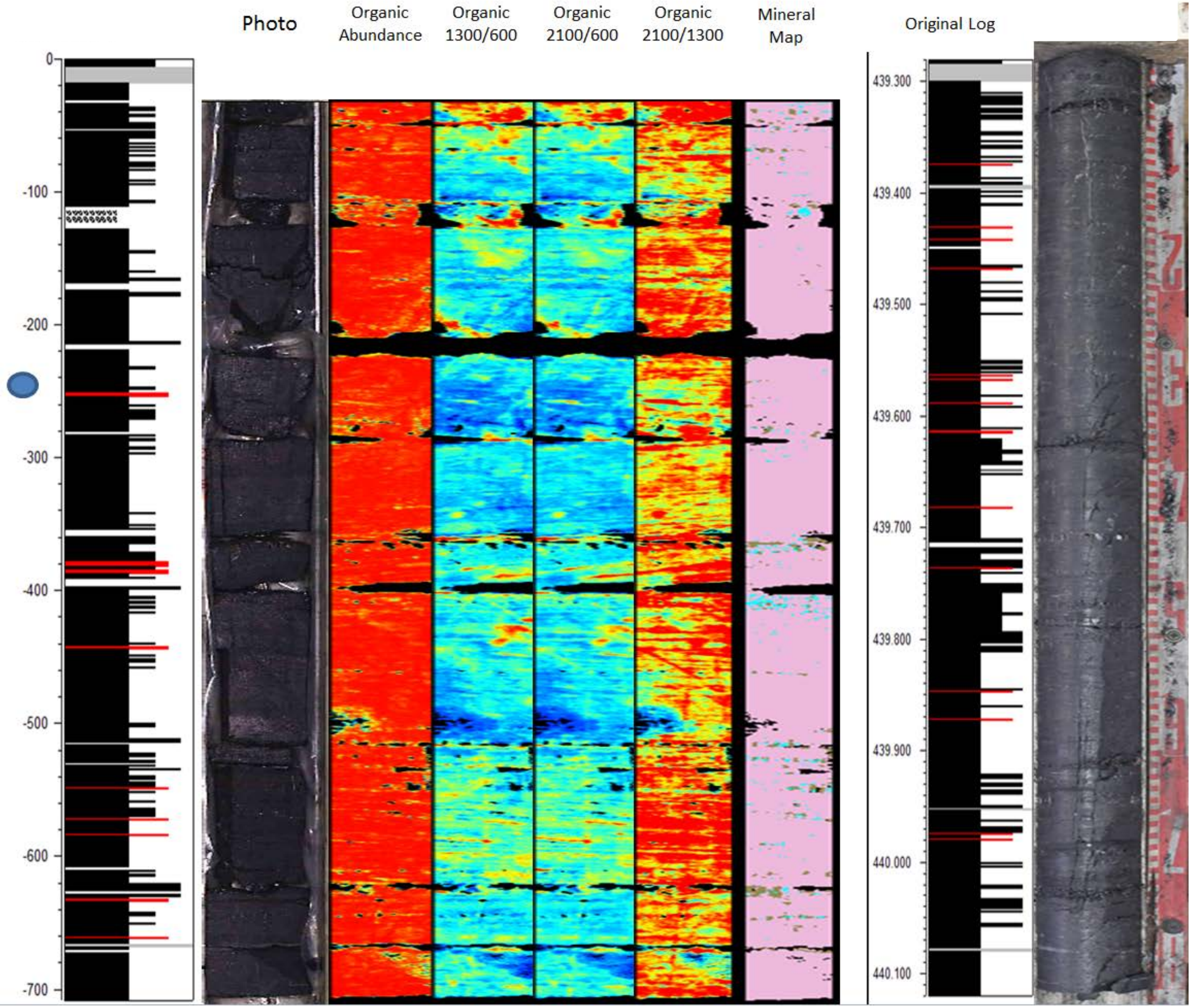
Corescan TM Output Organic Interpretation- Do these peak ratios represent lithotypes?

Dull, dark blue 1300/600, 2100/600, variable intensity 2100/1300



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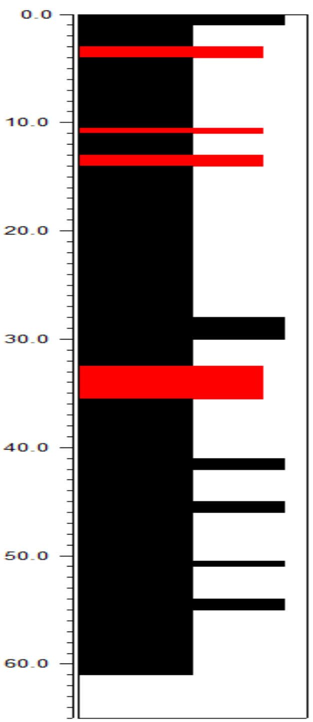
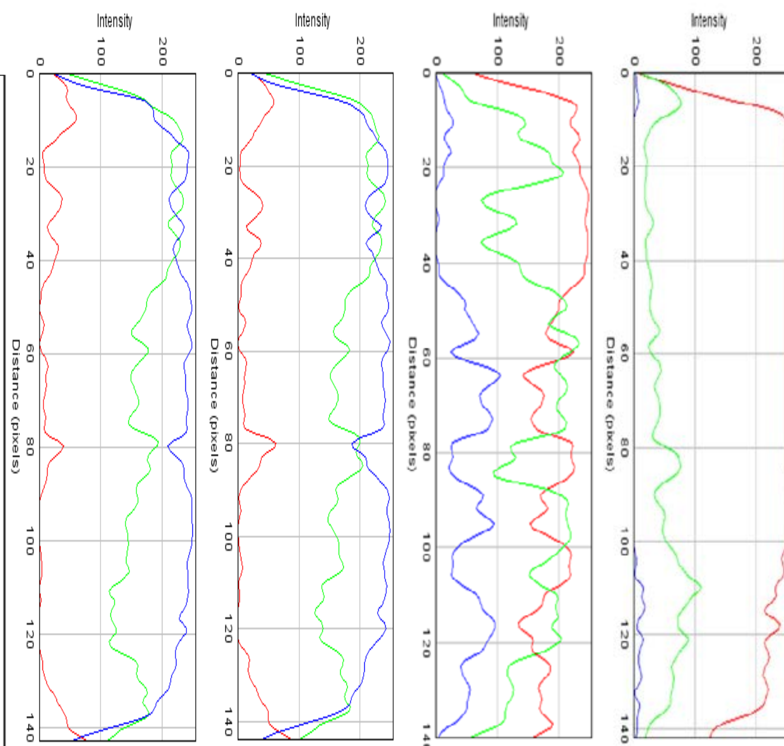
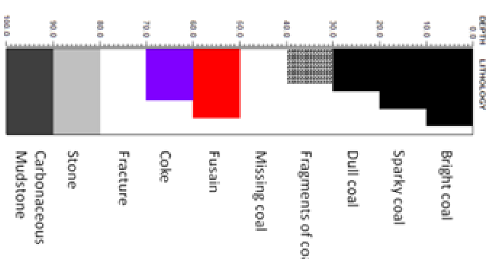
Corescan ™ Output Organic Interpretation-deconstruct the image into red, green, blue

Corelog

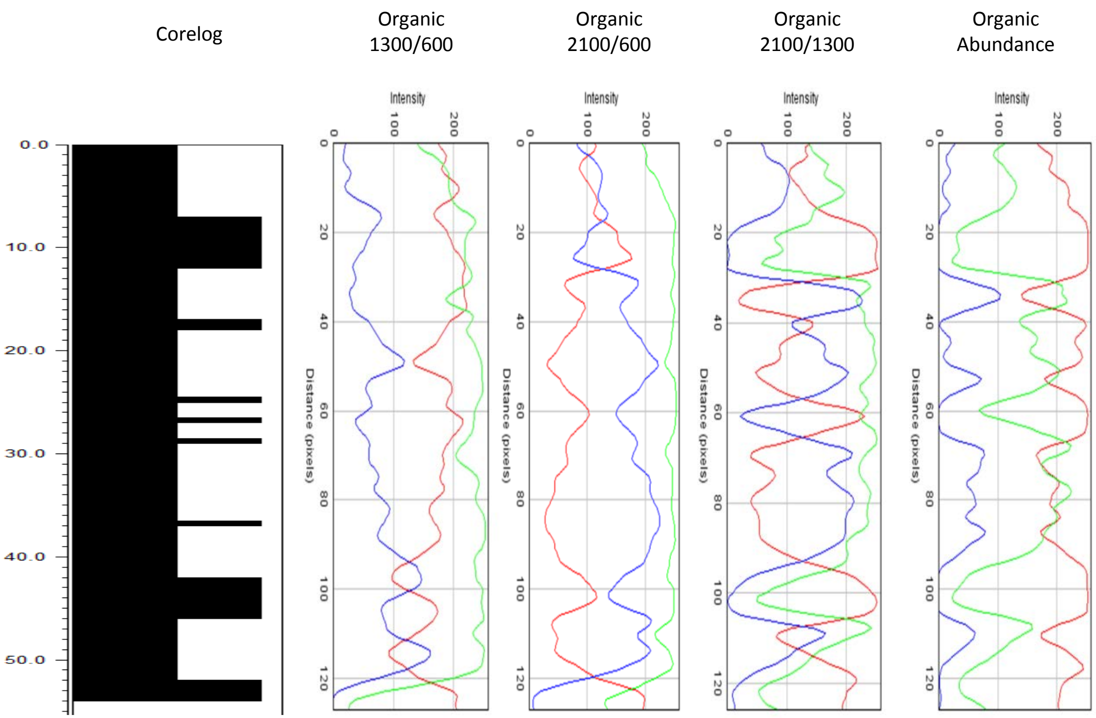


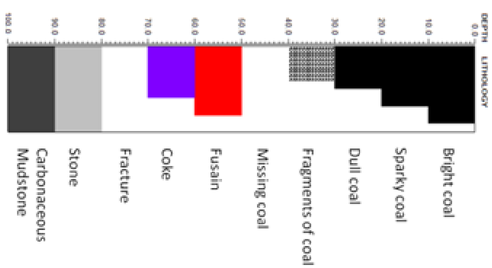
Organic 1300/600 | Organic 2100/600 | Organic 2100/1300 | Organic Abundance





Corescan ™ Output Organic Interpretation-deconstruct the image into red, green, blue





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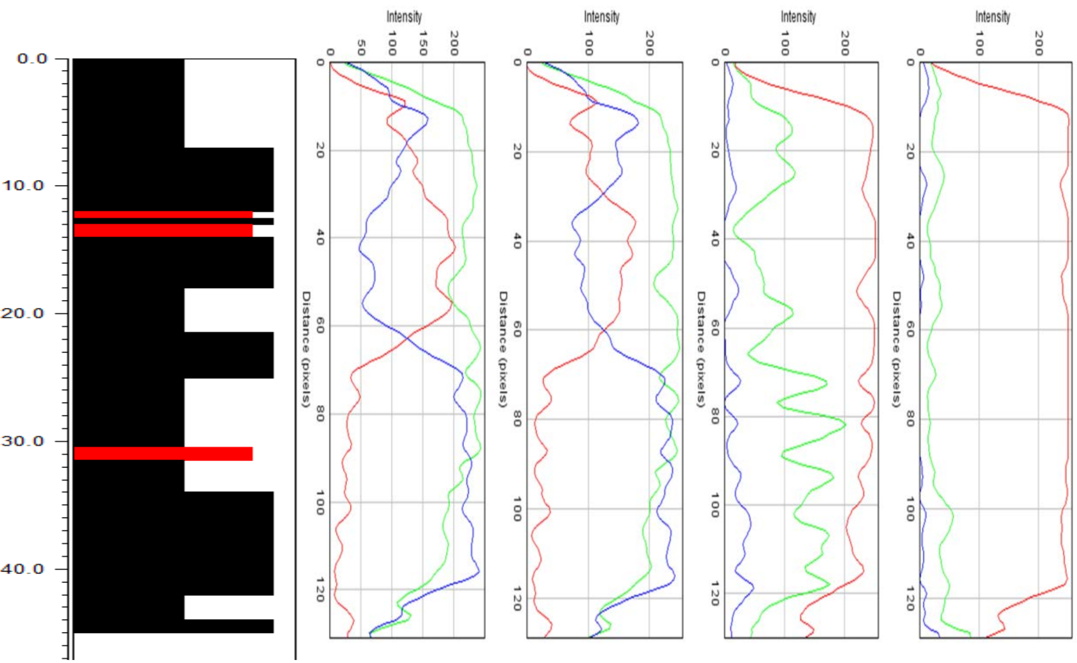
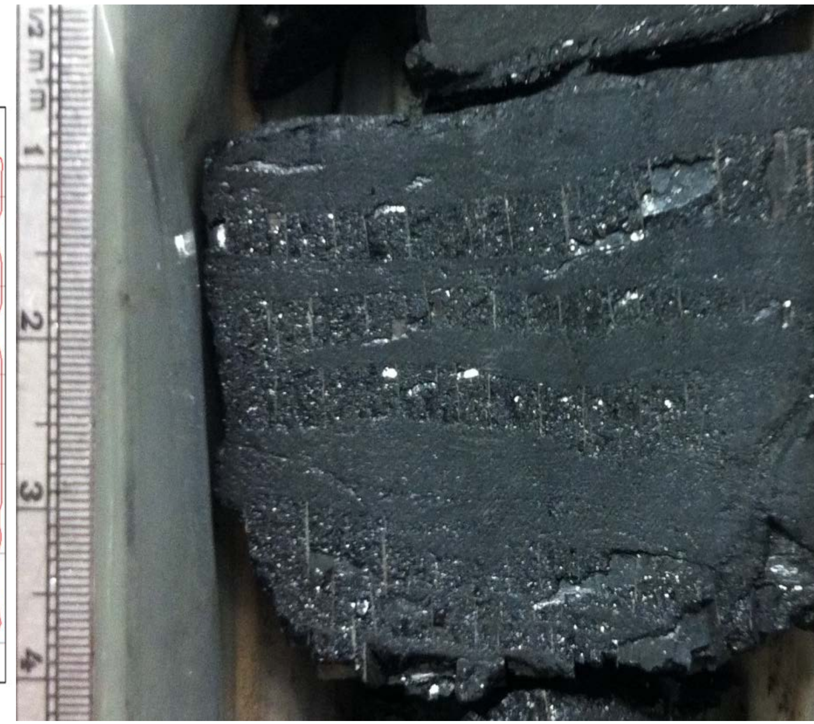
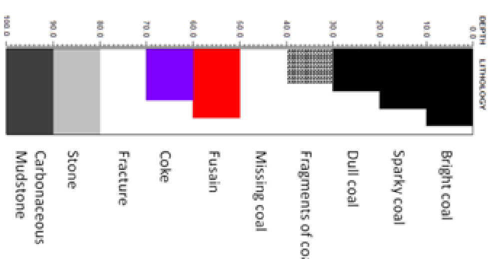
Corescan ™ Output Organic Interpretation-deconstruct the image into red, green, blue

Corelog | Organic 1300/600 | Organic 2100/600 | Organic 2100/1300 | Organic Abundance







Not convinced?

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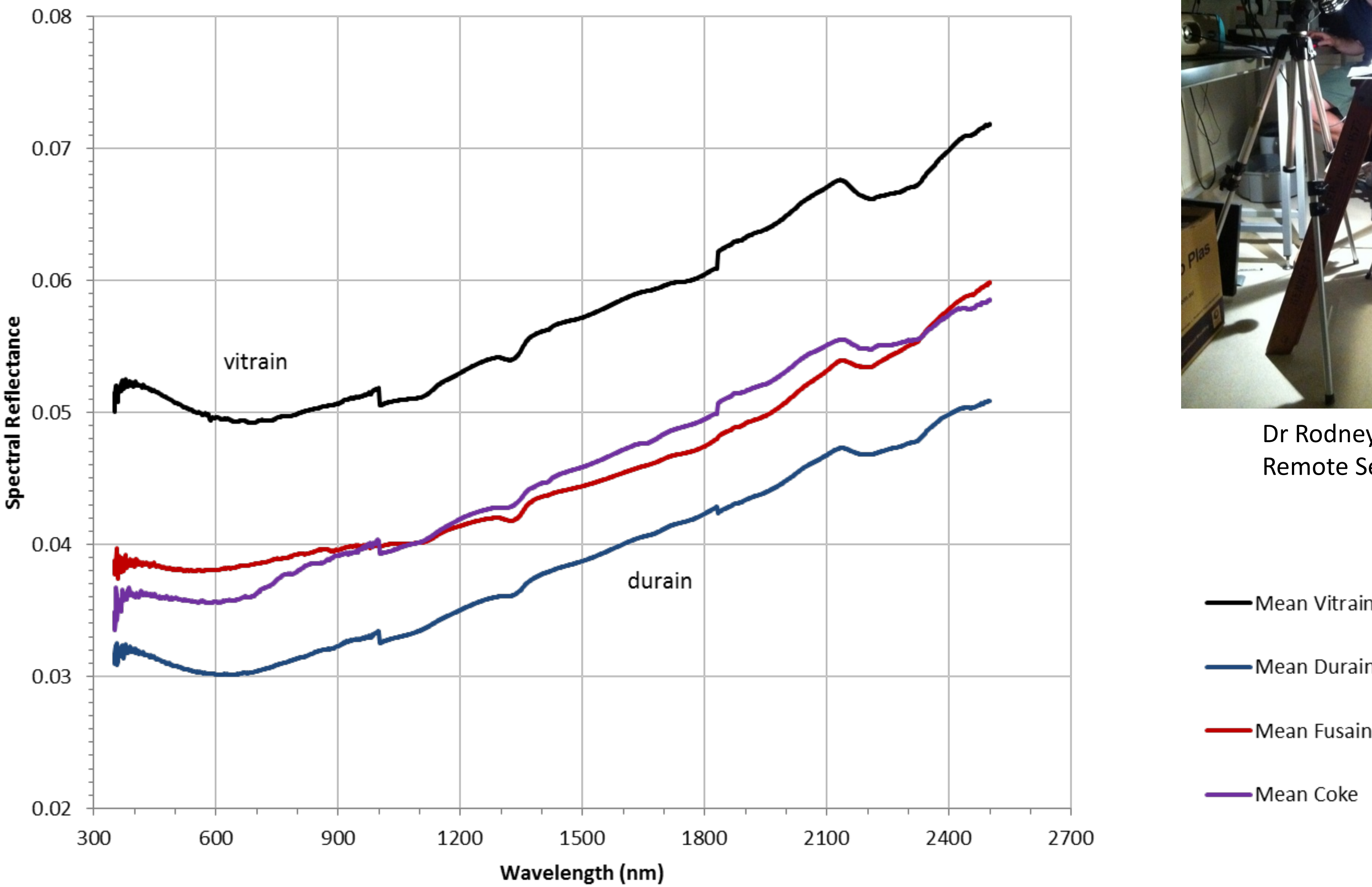
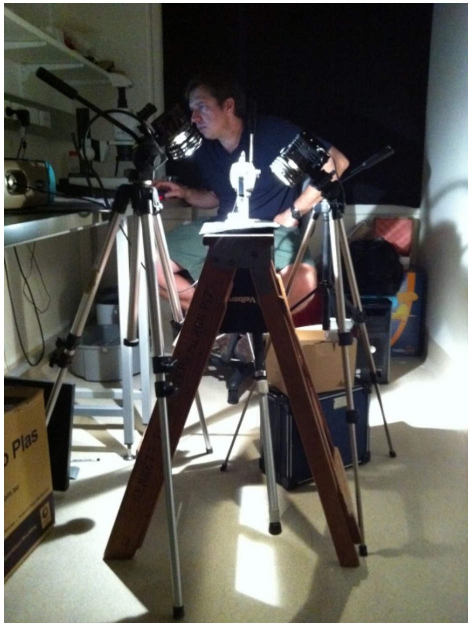
ASD Field Spectrometer study of Lithotypes-

Vitrain is shinier than durain, but not specific to a wavelength





Dr Rodney Borrego (PHD Remote Sensing

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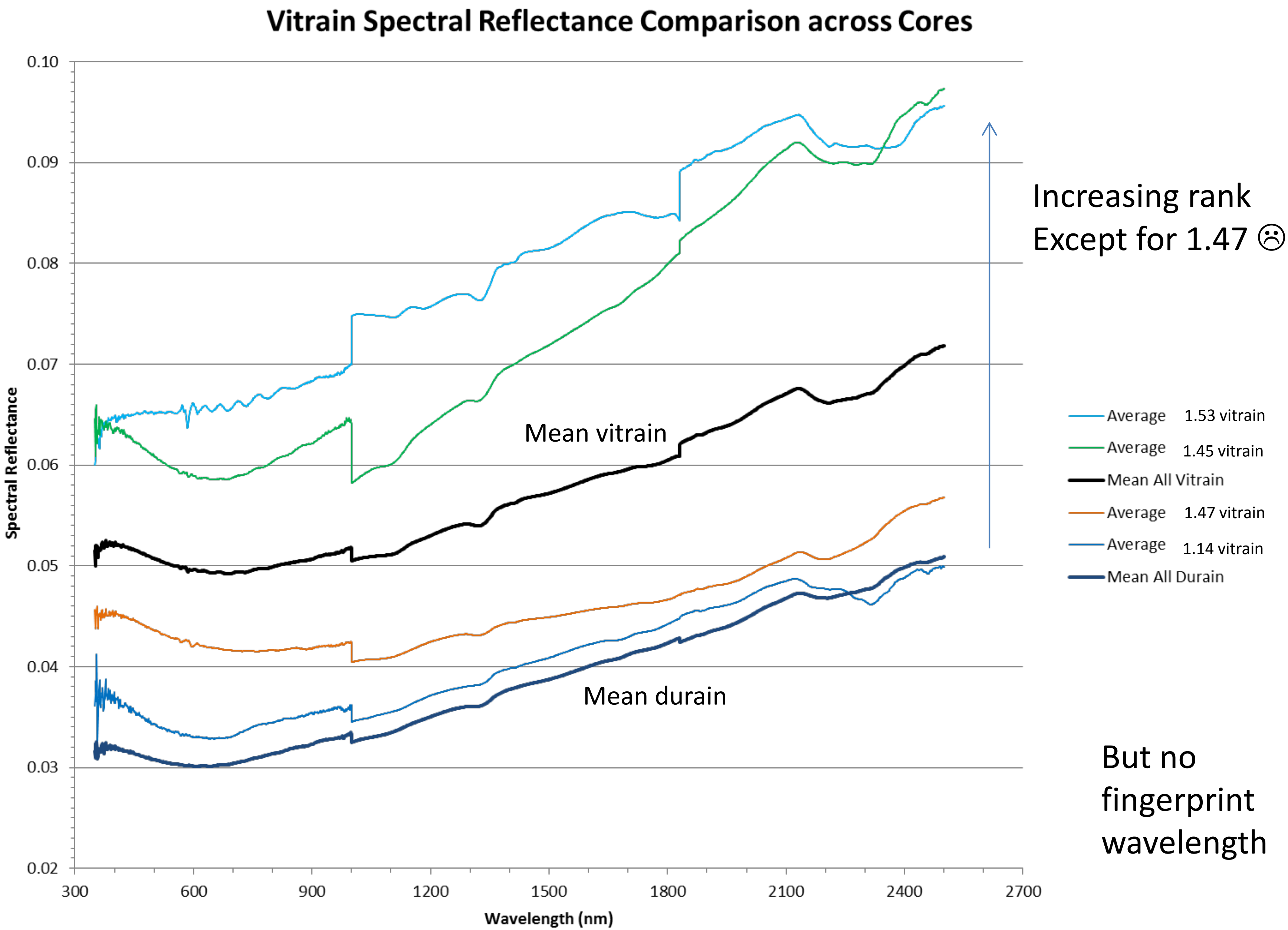

Increasing rank
Except for 1.47 ☹

But no fingerprint wavelength

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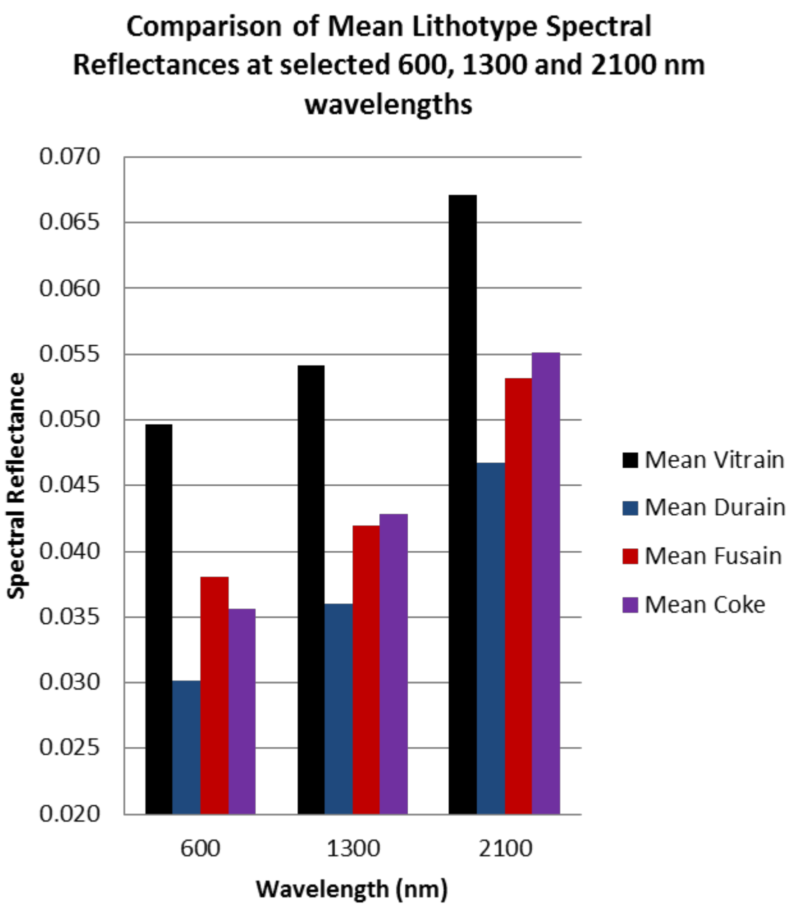
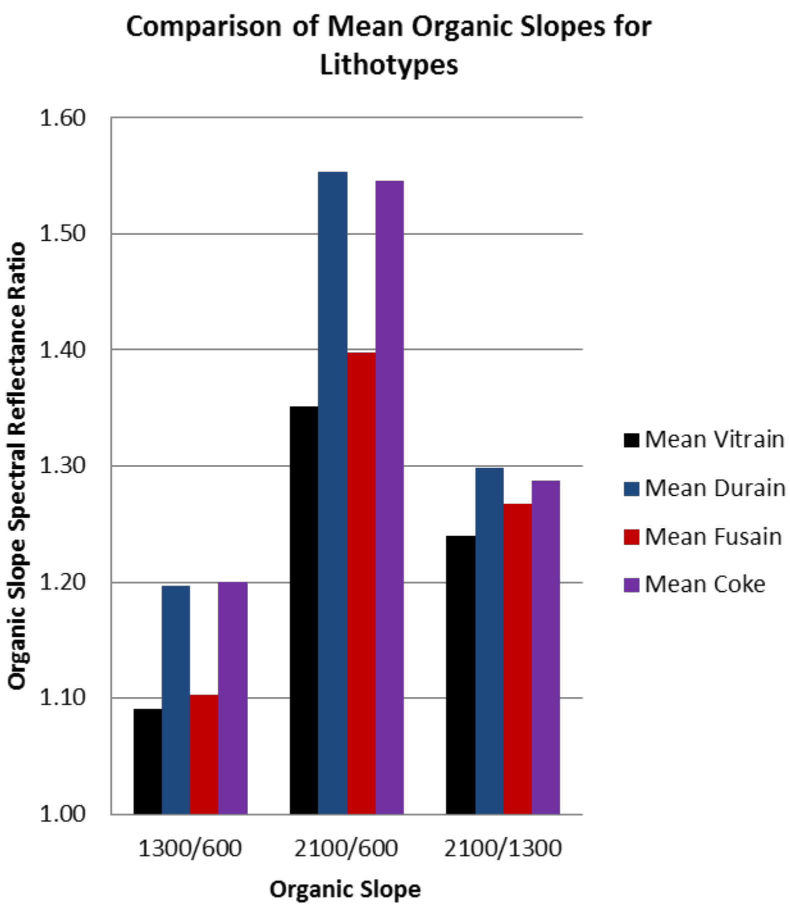
ASD Field Spectrometer study of Lithotypes-

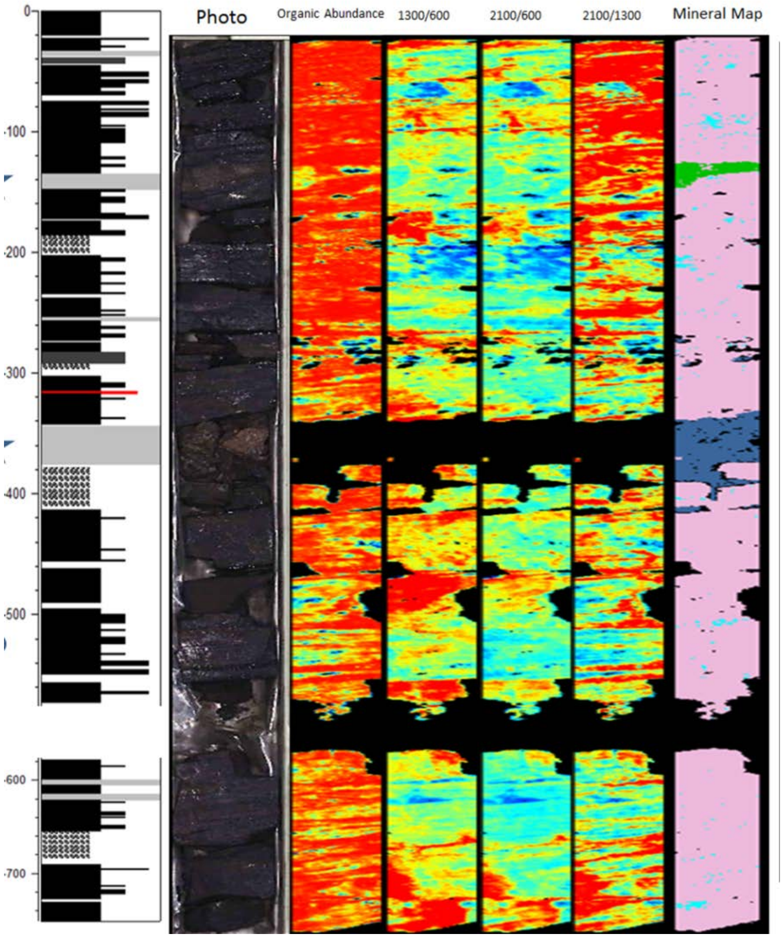
All wavelengths responded moreso to rank than type, but the intensity can pick up lithotype differences





Conclusions- it's promising

- Minerals can be identified in bands, lenses and the fine cleat systems, but needs further validation work to fine tune the spectral libraries
  - Addition of TIR to the detector range would assist
- The organic slope ratios (?C and O bond stretching) are detecting changes in coal lithotype, but not always consistent
  - Normalisation of spectra by reflectance may assist in improving discriminations
  - Additional work on texture/roughness using the occurrence of cleat mineralisation can assist in some coals but not all
- Rank, by spectral reflectance, can be estimated in the core, but broader rank range required to validate this claim
- Other parameters, such as coal/rock quality designation (# fractures or intact 10mm core per linear meter) could be extracted from the profilometer



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Acknowledgments

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- Dr Jon Huntington for fruitful discussions

Questions?

Senior author Dr Natalya Taylor: Dentist, flight lieutenant, geologist