Evaluation of Spectral Proxies in Unconventional Hydrocarbon Plays: A Case Study from the Southern Georgina Basin, Australia*

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Abstract

The Georgina Basin is a Neoproterozoic–Paleozoic basin in northern Australia, covering approximately 325,000 km^2 and straddling the Queensland and Northern Territory border. A thick Cambro-Ordovician succession of marine carbonates in the southern part of the basin hosts several prospective source units that are associated with shales. The main unconventional target is the Middle Cambrian Arthur Creek Formation (ACF). In this study, we examine the utility of HyLoggerTM data for the characterisation of unconventional hydrocarbon source rocks and reservoirs in the southern Georgina Basin. We also evaluate whether spectral proxies can be developed for key data types (e.g. total organic carbon (TOC) and total gamma response) by integrating the HyLogger™ data with existing well log, mineralogical and geochemical data. The automated HyLoggerTM technologies use reflectance spectroscopy to map relative changes in key mineral species in drill core and cuttings. Three spectrometers in the HyLoggerTM instrument measure spectral responses across the visible-near-infrared (VNIR), short-wave infrared (SWIR), and thermal infrared (TIR) wavelengths for oxide, hydroxide and carbonate, and anhydrous silicates respectively.

Previous use of HyLoggerTM data has largely been restricted to mapping mineral alteration assemblages for mineral exploration; however, the data have excellent potential for petroleum applications. Initial results are promising: there is an apparent relationship between gamma intensity, core SWIR albedo (mean SWIR reflectance), aspectral SWIR response and quartz content in the lower ACF. Peaks in gamma intensity broadly align with troughs in SWIR albedo, suggesting that the reduced albedo is a result of increased TOC content. This has been confirmed by Rock-Eval 6 measurements of organic content in the lower ACF, thus developing a HyLoggerTM TOC spectral proxy appears possible. The HyLoggerTM data also illustrate distinct mineralogical variations associated with sedimentary cyclicity in the middle ACF in the Toko Syncline. Peaks in gamma intensity appear driven by an increase in anoxic, quartz-rich sediments and a decrease in carbonate

contribution, and are also associated with decreased core SWIR albedo and spectral contrast. Thus HyLoggerTM data support log-derived paleo-environmental interpretations, and illustrate the excellent potential of HyLoggerTM mineralogical and spectral data for characterising unconventional hydrocarbon reservoirs.

References Cited

Ambrose, G.J., P.D. Kruse, and P.E. Putnam, 2001, Geology and hydrocarbon potential of the southern Georgian Basin, Australia: APPEA Journal, v. 41/1, p. 139-163.

Willink, R., and M.G. Allison, 2015, Exploring for unconventionals in the Georgina Basin: Will the real Arthur Creek Formation hot shale please stand up!: AAPEA Conference and Exhibition, May 17-20, Melbourne, Australia.

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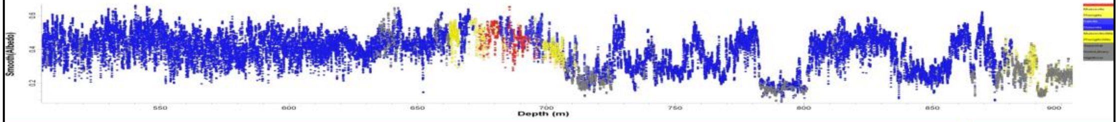
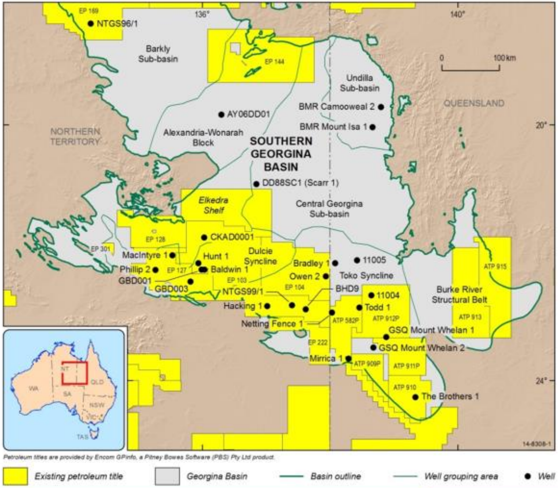
Outline

- Introduction to the Georgina Basin
  - Petroleum prospectivity and key challenges
- HyLogging technique introduction
  - Mineralogy and spectral information
- Results: Application of HyLogger data in the Georgina Basin
  - Mapping mineralogy and albedo across the basin
  - Evaluation of albedo as a proxy for TOC



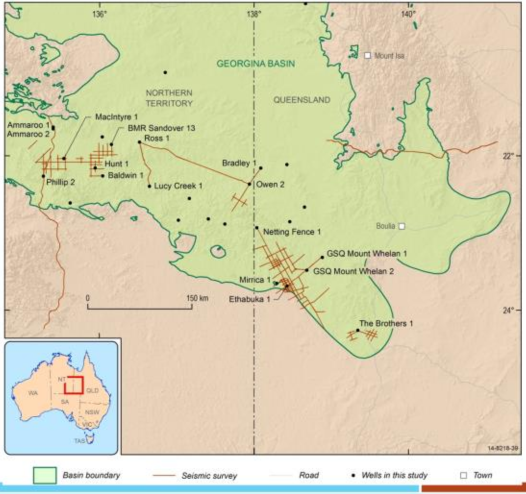
Georgina Basin overview

- Two key depocentres containing Neoproterozoic and Lower Paleozoic carbonate sediments (Dulcie and Toko Synclines)
- Middle-Cambrian petroleum system - Thorntonia Limestone, **Arthur Creek Fmn**. and Arrinthrunga Fmn.
- Organic-rich shales with TOC up to 16% in Dulcie and Toko zones
- Prospective for conventional and unconventional oil and gas: Statoil (PetroFrontier JV; Baraka), Central Petroleum (Total JV)

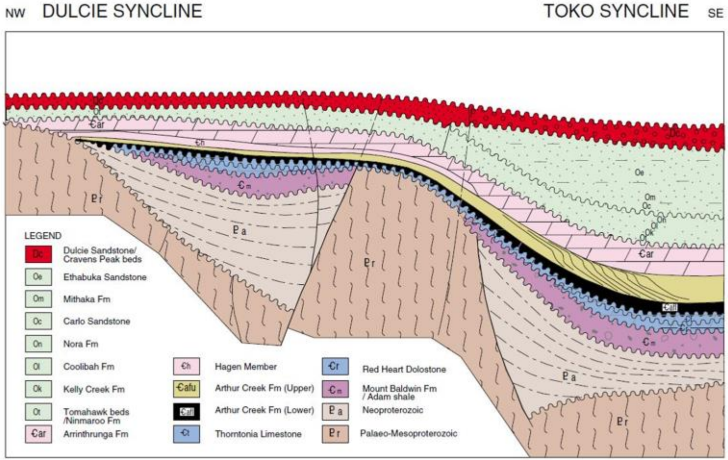


Challenges in the Georgina Basin

- No seismic lines that cross the whole basin (industry have recently acquired more but this is still confidential)
- Limited sequence stratigraphic interpretations in the basin
- Many unconformities and disconformities amongst the sequences
- Basin is across NT and QLD

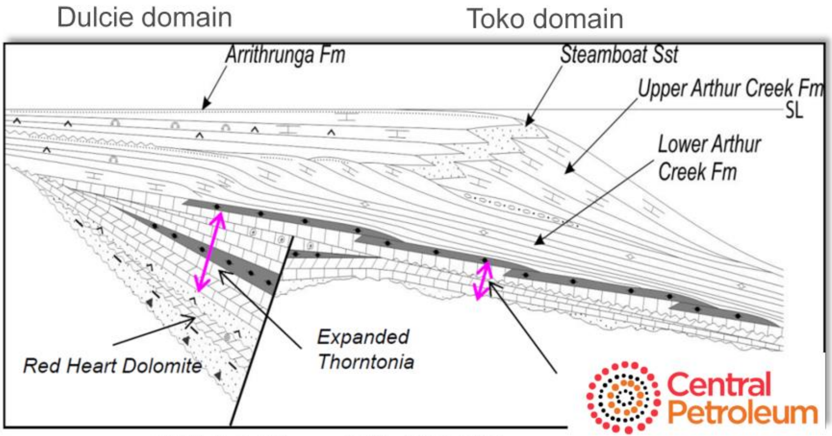


Previous understanding of the hot shale



Ambrose et al., 2001, APPEA Journal

New understanding: TWO hot shales in the basin



Willink & Allison, 2015 (APPEA)

Project aims

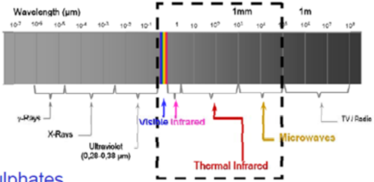
1. Evaluate the mineralogical properties of the key source rock units in the Georgina Basin (c.f. the Arthur Creek Formation; Thorntonia Limestone) and map these formations across the basin;
2. Evaluate relationships between HyLogger spectral data and other data types (geophysical, organic geochemistry, mineralogy, and geomechanical properties) – can spectral proxies be developed for TOC?

HyLogging technique overview

- Objective mineralogical characterisation of drill-core
- Based on reflectance spectroscopy sensing molecular level properties of different minerals: three spectrometers – VNIR, SWIR and TIR
- Reflectance = ratio of reflected energy to incident energy; varies with wavelength
- Automated logging technique (up to 700 m core/day)
- Spectrometer spatial resolution ~ 8 mm; approx .100 ‘samples’/ metre
- The Spectral Geologist (TSG) software turns raw HyLogging data into mineralogical distributions – initial interpretation is automatic
- It provides relative proportions (not modal abundances) unless calibrated against external standards.

Spectral regions and mineral identification

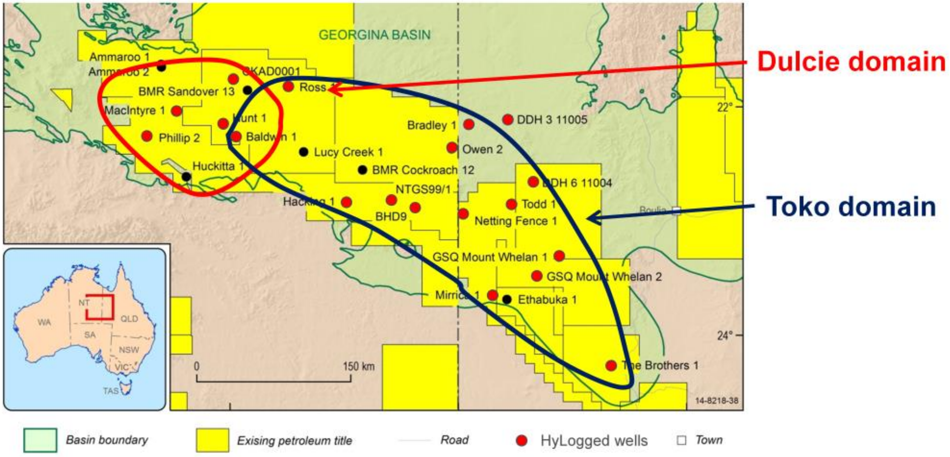
- **Visible and near infrared** (VNIR)
  - 400 - 1000 nm
  - Iron oxides (Hematite, Goethite, Jarosite)
  - REEs
  - Vegetation



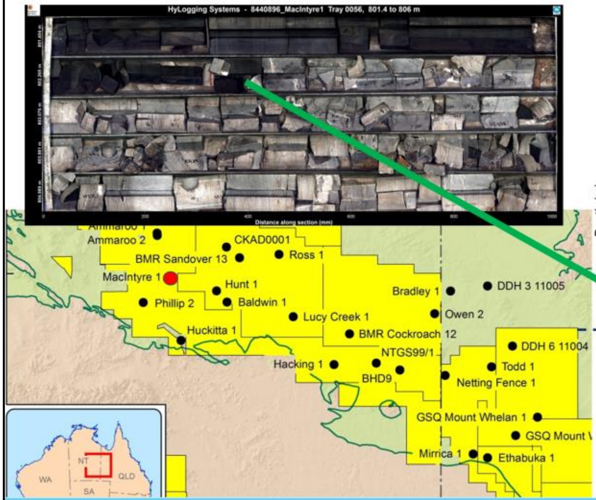
- **Shortwave Infrared** (SWIR)
  - 1000 - 2500 nm
  - (OH) bearing minerals
    - Clays, phyllosilicates, amphiboles, sulphates
  - Carbonates

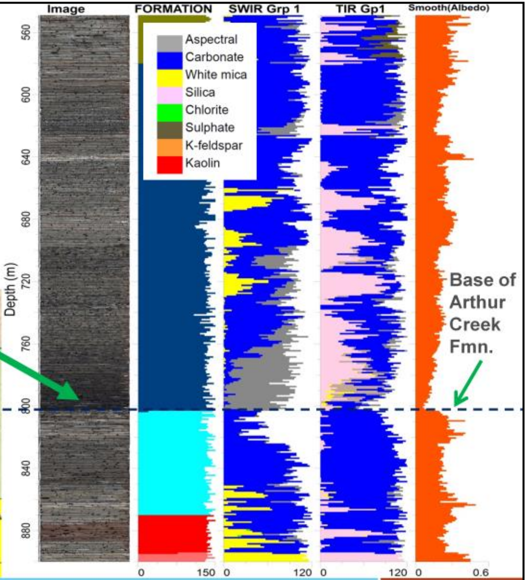
- **Thermal Infrared** (TIR)
  - 8000 - 12000 nm
  - Silicates: quartz, feldspars, garnets, pyroxenes
  - carbonates

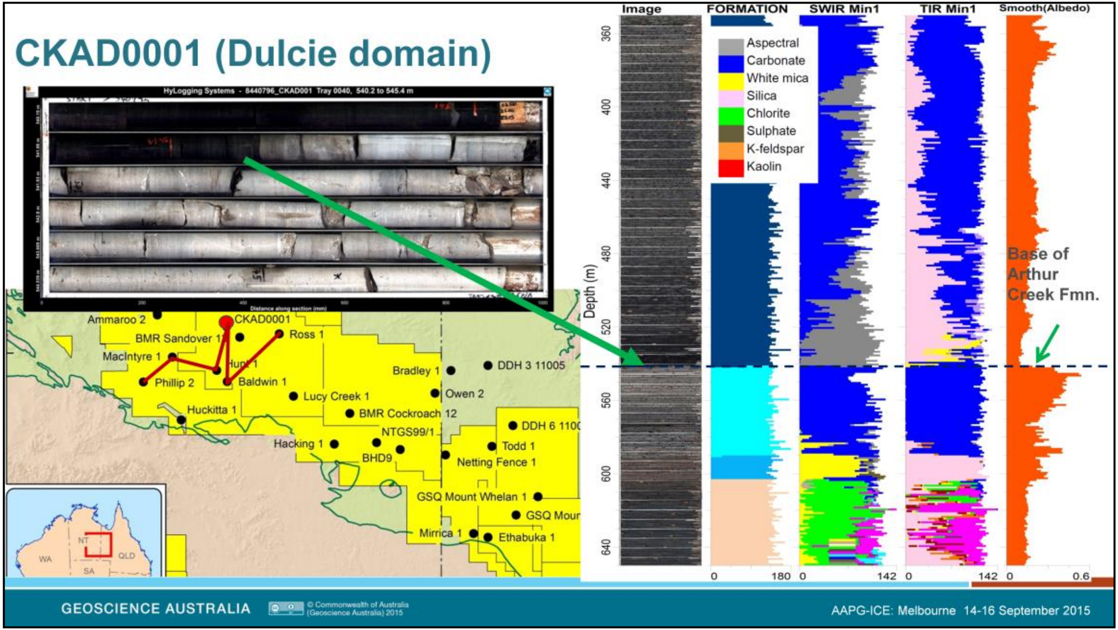
1. Mapping mineralogy & albedo across the Georgina



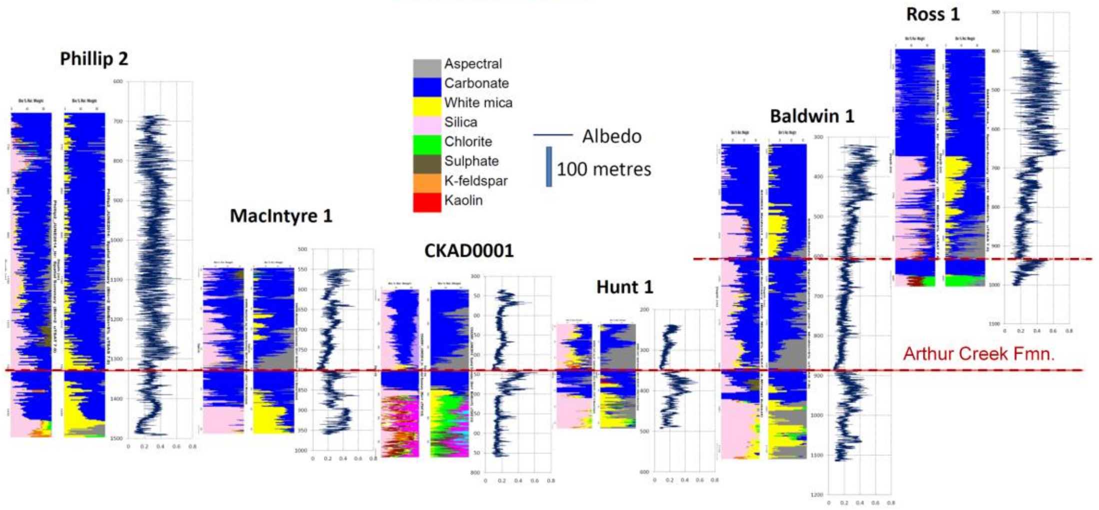
MacIntyre 1 (Dulcie domain)



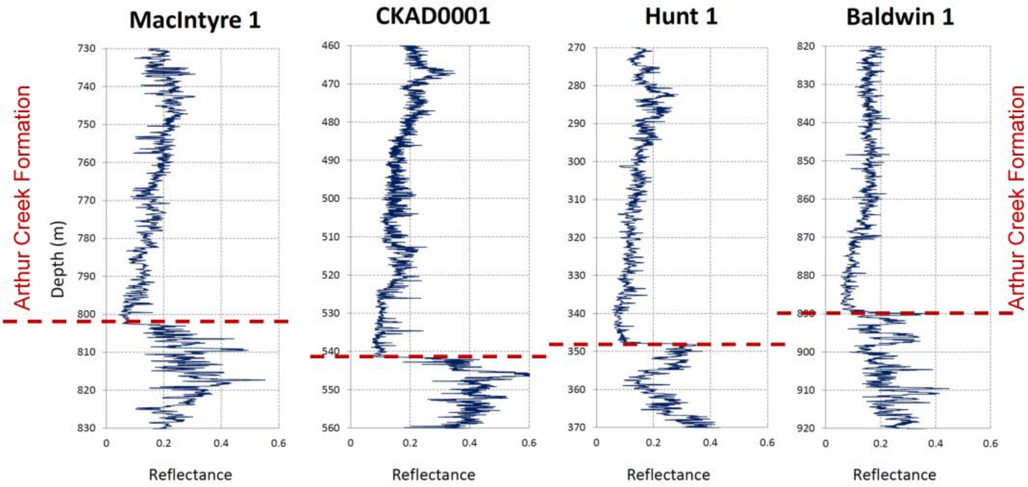




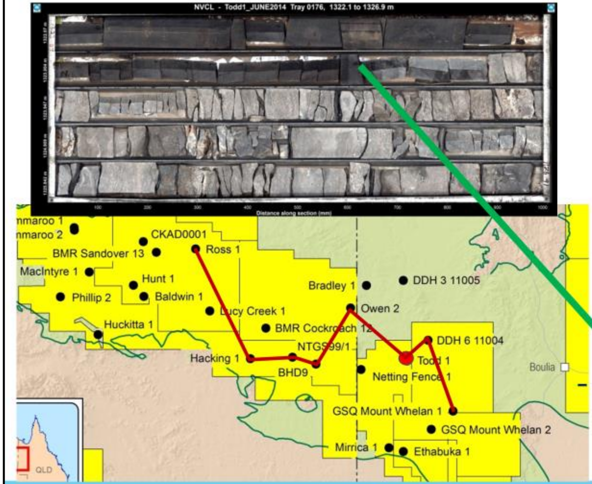
Presenter's notes: Introduce the concept of 'aspectral' – how it results and the relationship with reflectance -> albedo.

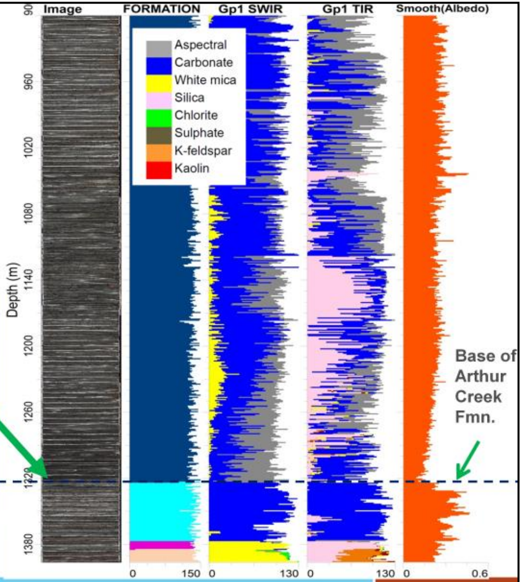

~West
Dulcie domain
~East
Ross 1
Phillip 2
Aspectral
Carbonate
White mica
Silica
Chlorite
Sulphate
K-feldspar
Kaolin
Albedo
100 metres
Baldwin 1
MacIntyre 1
CKAD0001
Hunt 1
Arthur Creek Fmn.

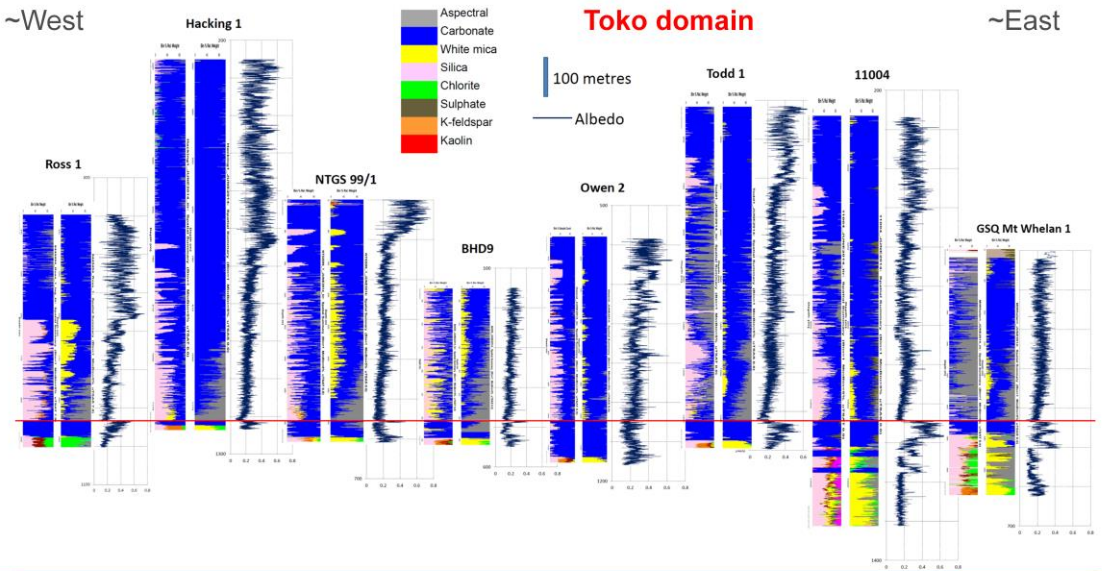
Albedo in the lower ACF: Dulcie hot shale



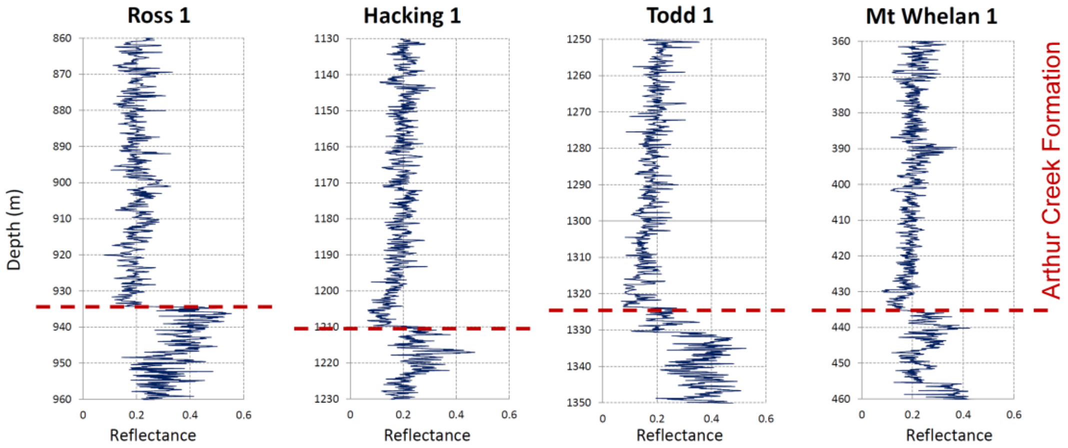
Todd 1 (Toko domain)





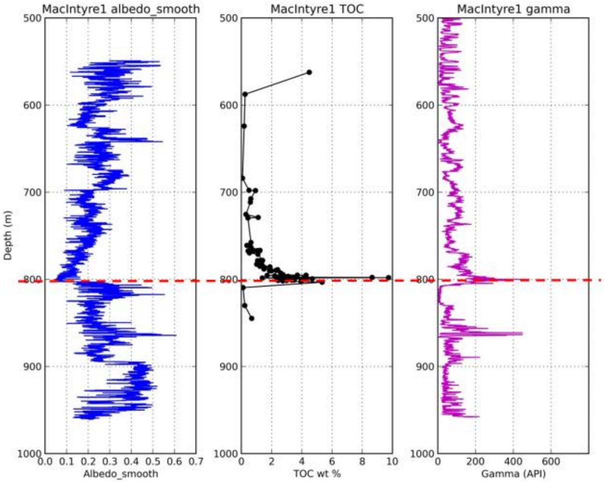

~West
Toko domain
~East
Aspectral
Carbonate
White mica
Silica
Chlorite
Sulphate
K-feldspar
Kaolin
100 metres
Albedo
Ross 1
Hacking 1
NTGS 99/1
BHD9
Owen 2
Todd 1
11004
GSQ Mt Whelan 1

Albedo in the lower ACF: Toko hot shale

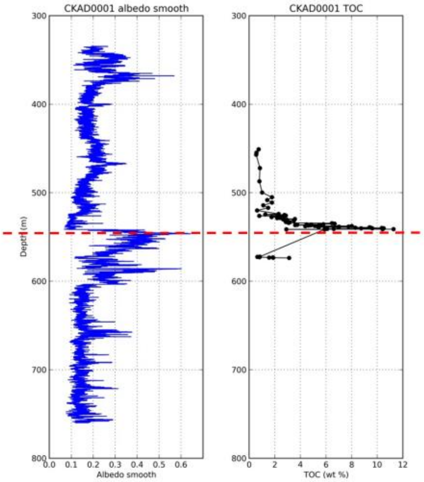


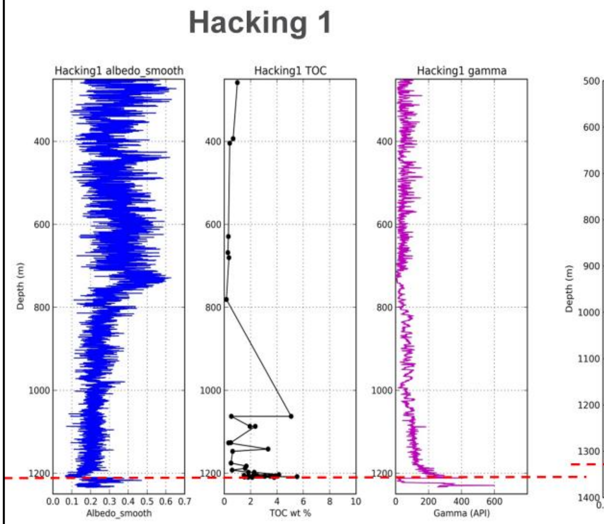
2. Evaluating albedo as a proxy for TOC

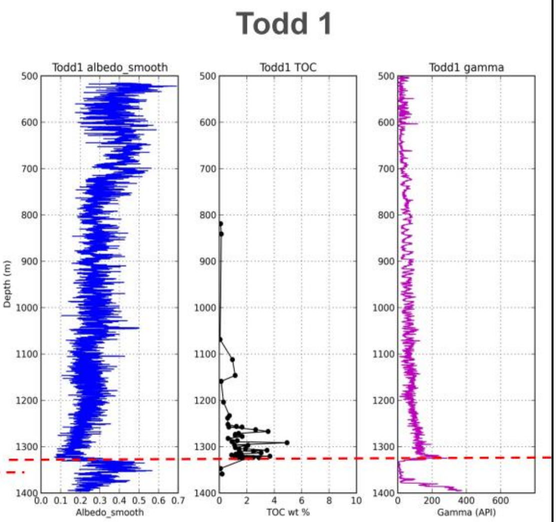
MacIntyre 1



CKAD0001




Hacking 1
Hacking1 albedo_smooth
Hacking1 TOC
Hacking1 gamma
Depth (m)
Albedo_smooth
TOC wt %
Gamma (API)


Todd 1
Todd1 albedo_smooth
Todd1 TOC
Todd1 gamma
Depth (m)
Albedo_smooth
TOC wt %
Gamma (API)

HyLogger Data Processing

1. HyLogger native sample resolution is 8 mm. The data were filtered with a low-pass filter (smoothed over 15 cm (= 19 samples)) to reduce the effect of variable sampling (i.e. core imperfections such as fine cracks, holes, edges can result in artificially-low reflectance readings)

2. Filtered data resampled to 15 cm resolution for statistical analysis

3. Different wavelengths of reflectance spectra were extracted:

   VNIR – SWIR (450 nm – 2450 nm) (basic channel outlier masking)

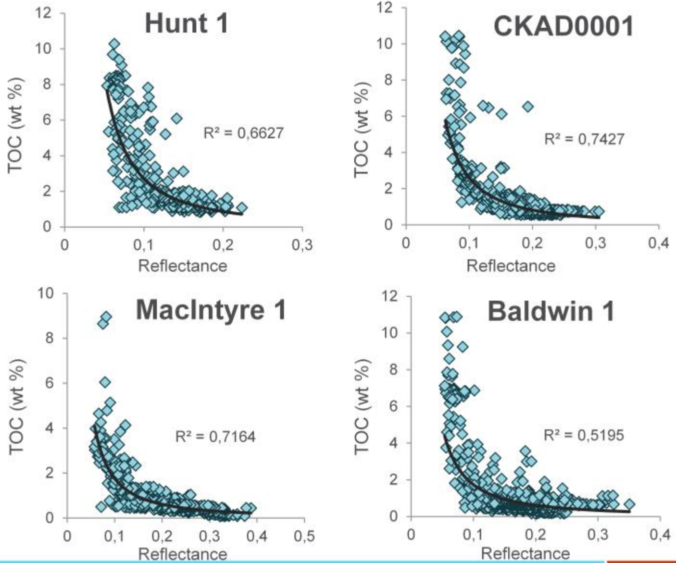
   Visible (450 – 750 nm)

   SWIR (1400 – 2450 nm)

4. Regression analysis conducted on lower part of the Arthur Creek Formation in 7 wells where sufficient organic geochemistry data are available

Results:

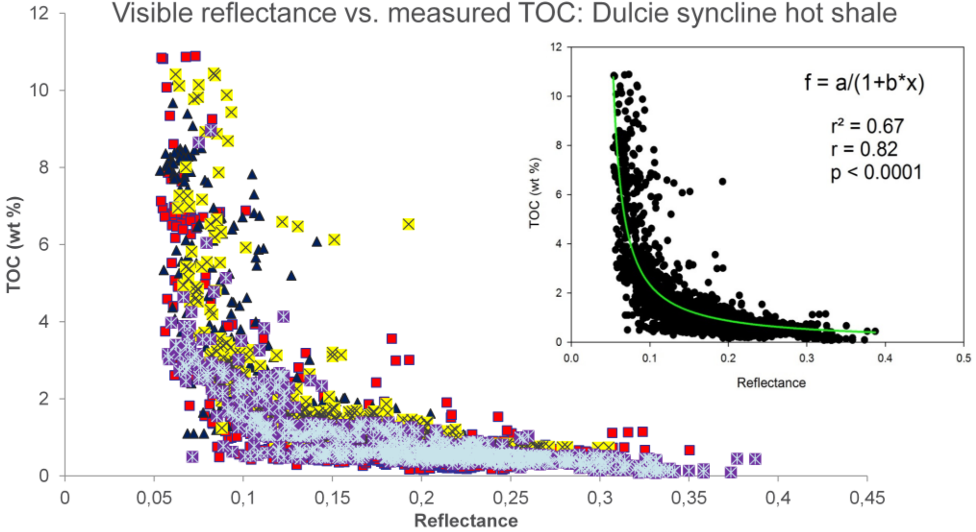
Dulcie hot shale



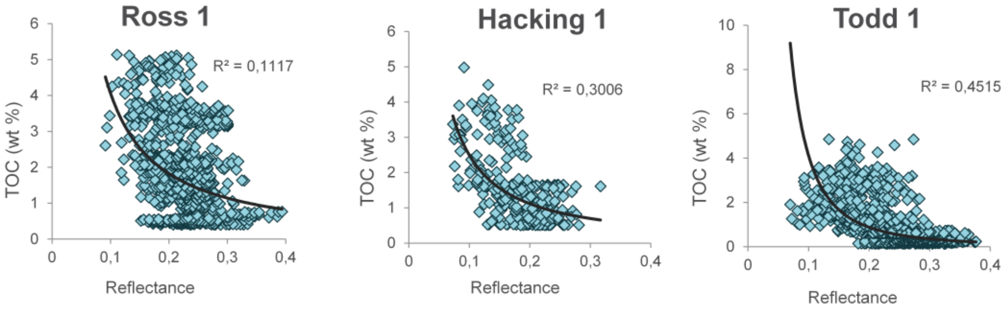
Presenter's notes:

1. The visible part of the spectra exhibit better correlations with TOC compared to the SWIR, and combined visible + SWIR.
2. Several wells exhibit clearer correlations between reflectance and TOC, however the relationship is not strong in some wells.

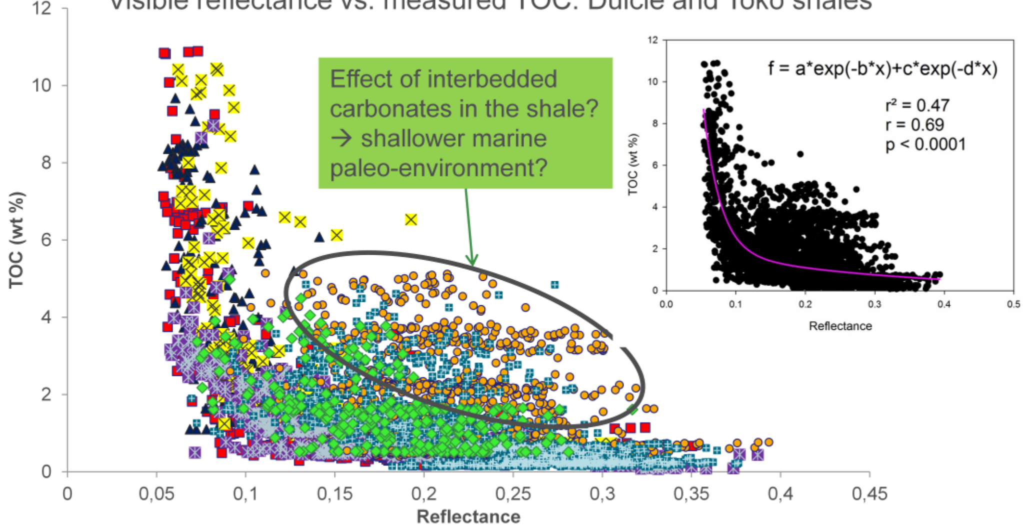
Visible reflectance vs. measured TOC: Dulcie syncline hot shale

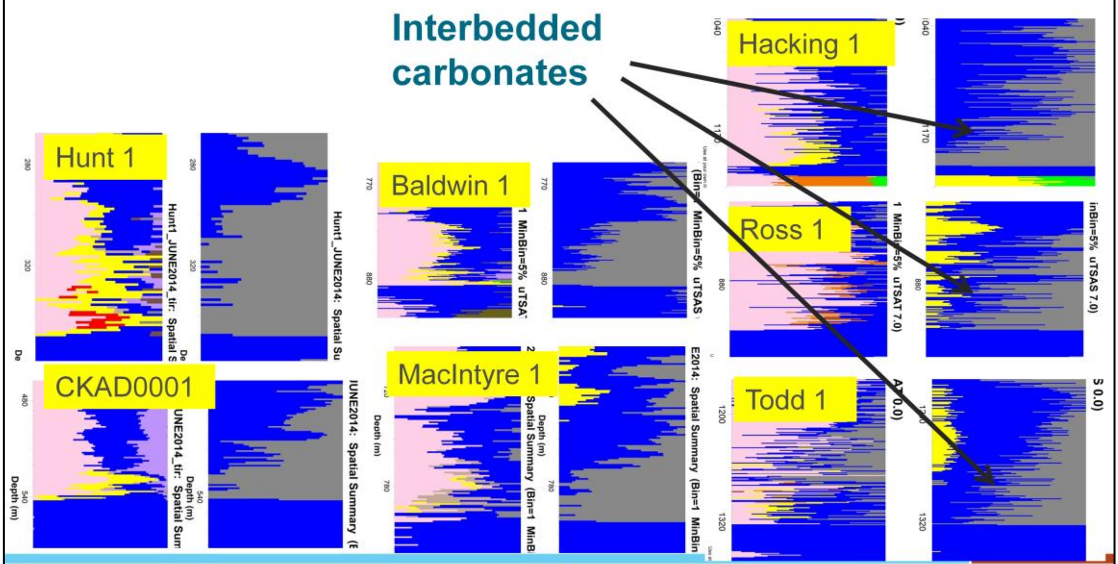


Results: Toko hot shale

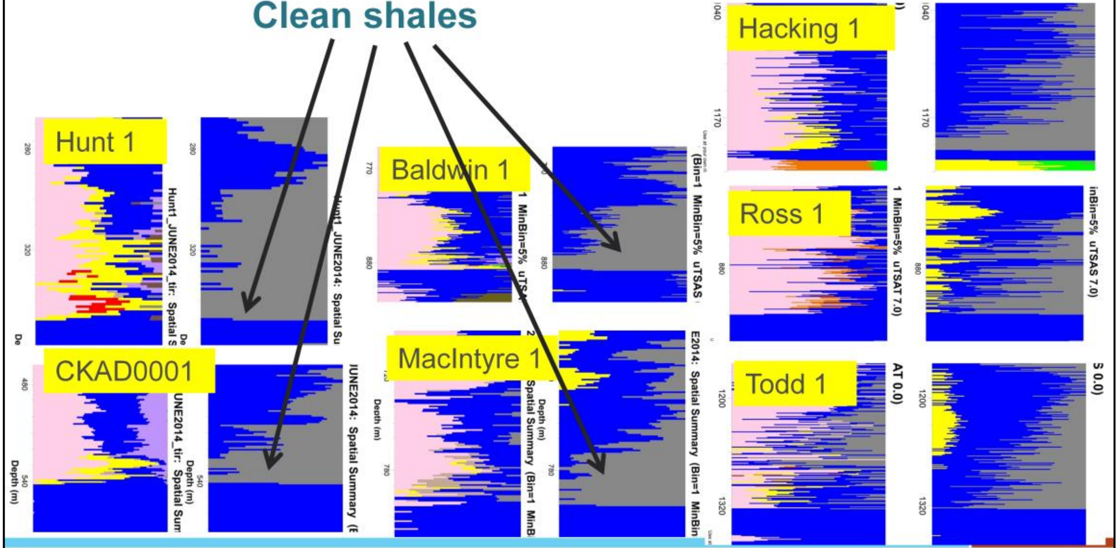


Visible reflectance vs. measured TOC: Dulcie and Toko shales



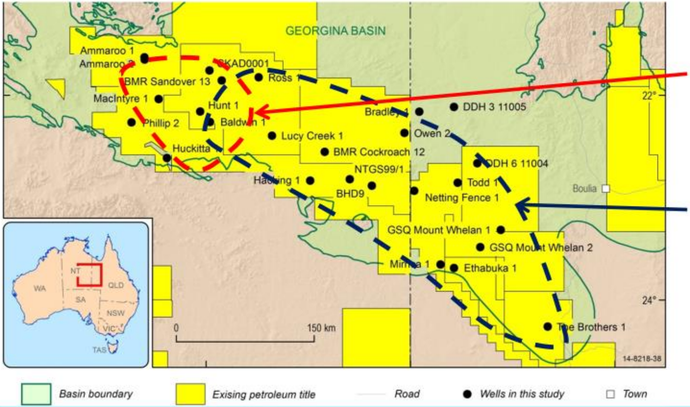

Interbedded carbonates
Hunt 1
CKAD0001
Baldwin 1
MacIntyre 1
Hacking 1
Ross 1
Todd 1

Clean shales



Conclusions

- The shales in the Georgina Basin are clearly mappable using HyLogger data – associated with an aspectral response in the SWIR



Conclusions

- The two shales in the Arthur Creek Fmn. are clearly distinguished on the basis of their mineralogical and spectral properties:
  - Dulcie hot shale is characterised by low albedo (~ 0.05 – 0.1), high TOC, low carbonate (= deep marine paleo-environment?)
  - Toko hot shale is characterised by higher albedo (~0.15 – 0.2), moderate TOC and interbedded carbonates (= shallower marine paleo-environment?)
- Albedo is significantly correlated with TOC in the Dulcie hot shale, and shows potential for use as a predictive proxy for TOC in the Dulcie domain. Albedo:TOC relationship in the Toko is less clear – not ideal for TOC prediction.

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Acknowledgements

- NTGS and GSQ – support in arranging HyLogging of Georgina Basin cores

Thanks for your attention

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