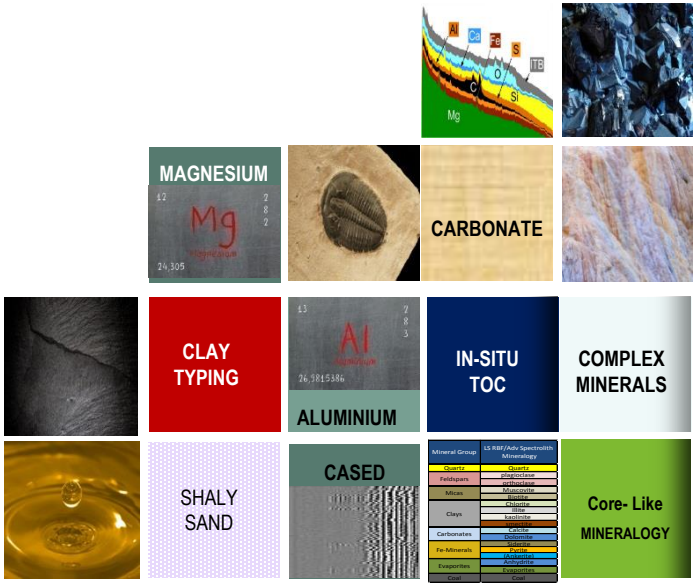
Aberdeen Formation Evaluation Society

Improved Cased-hole Formation Evaluation: The Added Value of High Definition Spectroscopy Measurement



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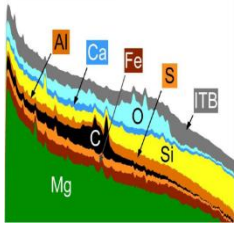
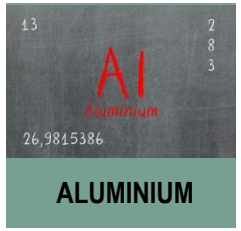
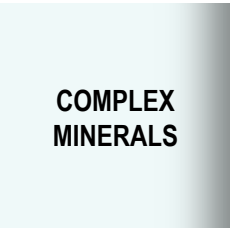
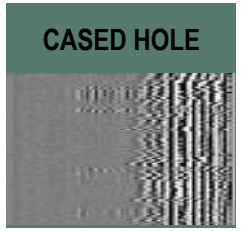
Outline

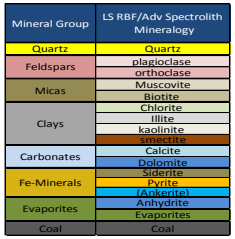
- Introduction
- High Definition Spectroscopy
- Technology Advances
- Cased hole examples
- Conclusions











Mineral Group	LS RBF/Adv Spectrolith Mineralogy
Quartz	Quartz
Feldspars	plagioclase
	orthoclase
Micas	Muscovite
	Biotite
Clays	Chlorite
	Illite
	kaolinite
	smectite
Carbonates	Calcite
	Dolomite
Fe-Minerals	Siderite
	Pyrite
	(Ankerite)
Evaporites	Anhydrite
	Evaporites
Coal	Coal

Introduction

- Boost of the daily crude production and accurate assessment of remaining potential in mature fields requires intelligent formation evaluation for extended reservoir life.
- Lithological uncertainties, structural complexity, depletion rates, well integrity issues, all effect current reserves estimate and field development plans.
- Cased-hole formation evaluation has a primary role for the proper description of the existing reservoir systems, to help finding that additional drop of oil or assisting completion design, intervention programs or plug and abandonment operations
- Current technology is the enabler, even in tough logging conditions.

The Role of Spectroscopy

- Recent developments on geochemical logging enable quantitative mineralogy determination for detailed description and extended range of application.
- High Definition Spectroscopy is successfully applied to better understand rock composition and improve reservoir models in complex lithology and harsh logging conditions.
- Providing critical contributions to development and production
  - Improved reservoir geomechanics
  - Rock properties for hydraulic fracturing
  - Clays typing to help stimulation, completion (fluids selection, flow control, etc)
  - Part of accurate overburden characterization for abandonment.

High Definition Spectroscopy

From Chemistry

- Enhanced elemental yields and dry weight

Element Symbol	Element Name	Capture	Inelastic
Al	Aluminum	●	●
Ba	Barium	●	●
C	Carbon		●
Ca	Calcium	●	●
Cl	Chlorine	●	
Cu	Copper	●	
Fe	Iron	●	●
Gd	Gadolinium	●	
H	Hydrogen	●	
K	Potassium	●	
Mg	Magnesium	●	●
Mn	Manganese	●	
Na	Sodium	●	
Ni	Nickel	●	
O	Oxygen		●
S	Sulfur	●	●
Si	Silicon	●	●
Ti	Titanium	●	

Elemental abundance in earth's crust

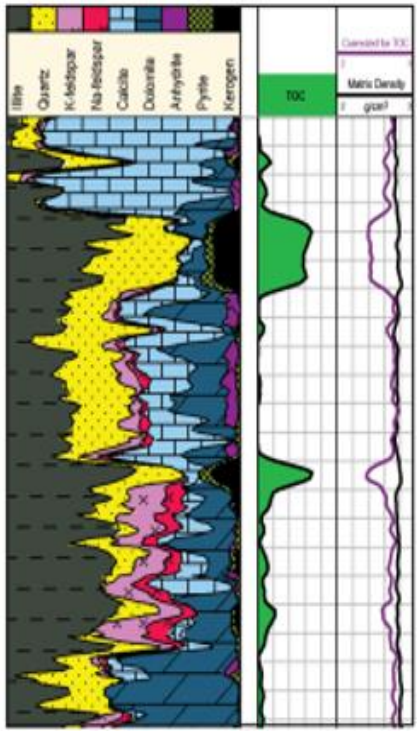
O 46.7
Si 27.6
Al 8.1
Fe 5.1
Ca 3.7
Na 2.8
K 2.6
Mg 2.1
S, Ti, Gd, Mn

> 99 %

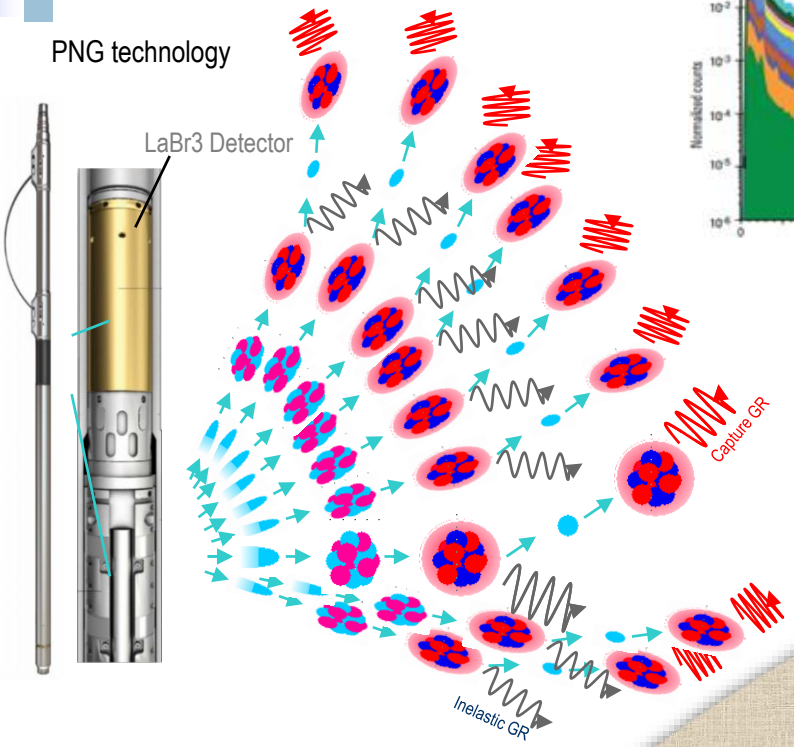
Carbon

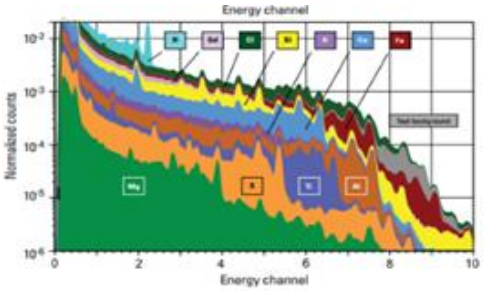
To Mineralogy and Saturations

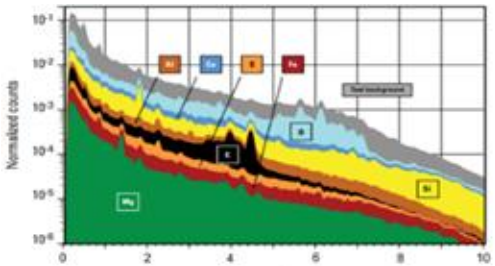
- Quartz, Calcite, Dolomite, Clays, Micas, etc.
  - Matrix, TOC, Sigma value



Spectroscopy Data Workflow







Spectral acquisition

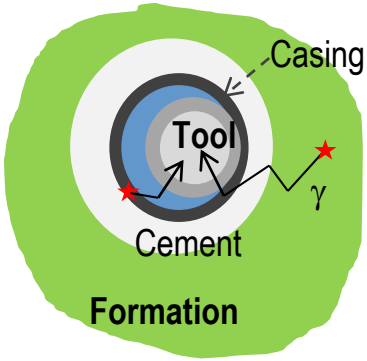
Spectral reconstruction

CH correction

Oxide closure

Minerals, matrix, TOC, sigma

Volumes, Saturation

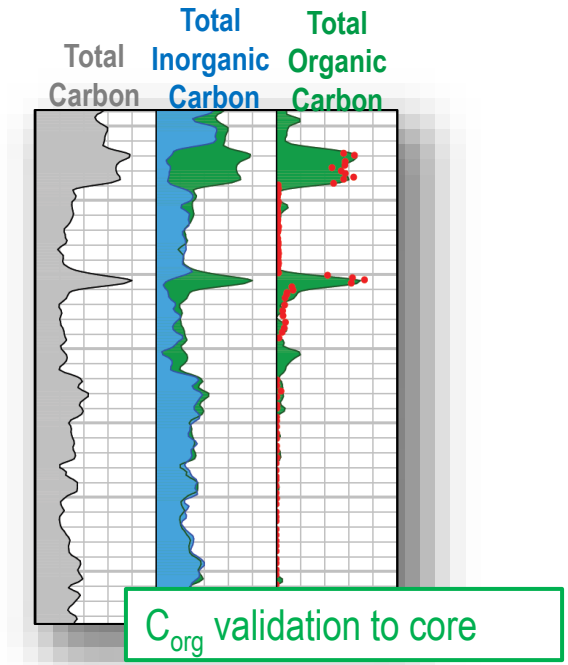


- Contribution from completion
  - Casing (Fe, …)
  - Cement (Si, Ca, …)
  - Scale (Ca, S, Ba, …)
- Additional GR scattering

Direct Approach to Hydrocarbon Saturation

- TOC = Total Carbon – Inorganic Carbon
  - Total Carbon is measured
  - Inorganic Carbon is derived from Minerals
  - TIC = 0.120*Calcite + 0.130*Dolomite + 0.104*Siderite + 0.116*Ankerite
- Saturation direct measurement from TOC

$$S_{hc} = \frac{TOC \cdot \rho_{ma} \cdot (1-\phi_T)}{\rho_{hc} \cdot X_{hc} \cdot \phi_T}$$

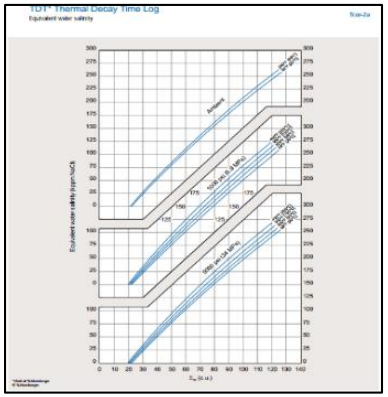


- Saturation from formation Sigma

$$SIGF = \phi \cdot Sw \cdot Sigm_{water} + \phi \cdot (1-Sw) \cdot Sigm_{hc} + (1-\phi) \cdot Sigm_{matrix}$$

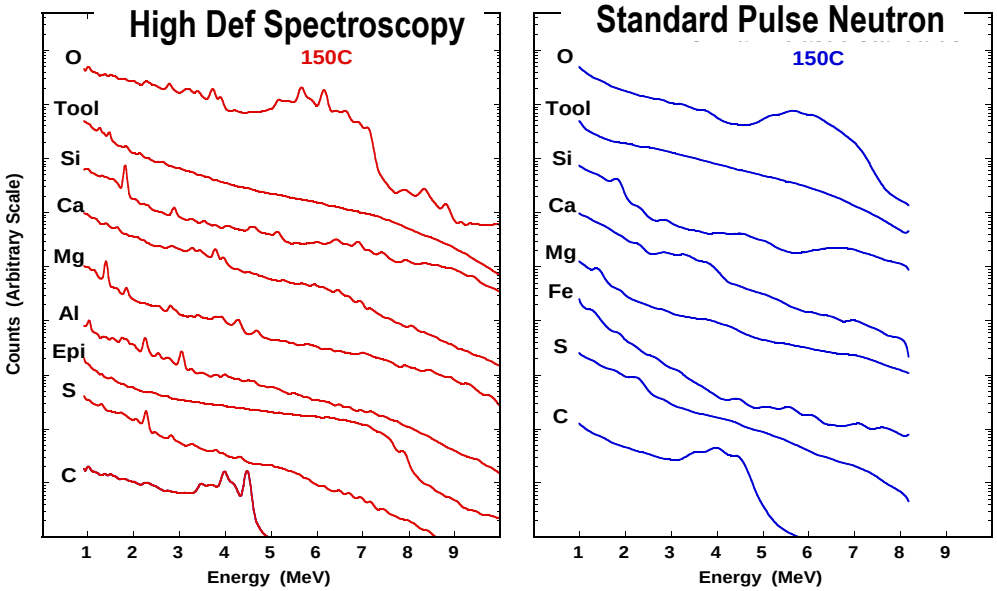
$$Sw = \frac{SIGF - \phi \cdot Sigm_{hc} - (1-\phi) \cdot Sigm_{matrix}}{(Sigm_{water} - Sigm_{hc}) \cdot \phi}$$

Sigma can also be converted to Salinity



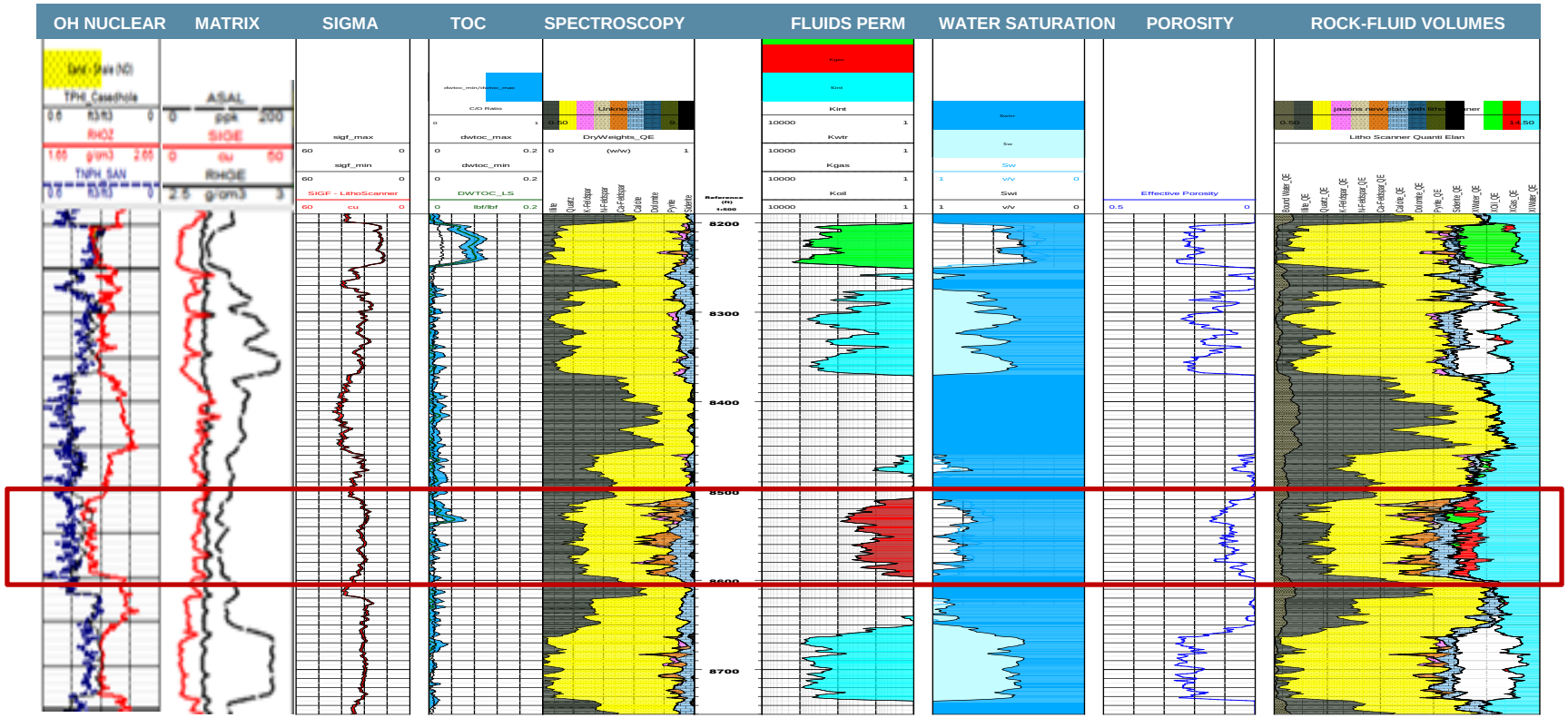
Improved Elements Analysis Behind Casing

- High efficiency $LaBr_3$ detectors
  - Improved resolution, statistics and logging speed
  - Cased-hole standards
  - No external calibration
- Electrical source
  - Green technology
- Pulsed & gated measurement
  - Clean separation of Inelastic and Capture spectra
  - In situ Total Organic Carbon (TOC) akin to CO PNL
  - Formation Sigma
  - Rock fluids plus rock matrix



Cased-Hole Formation Evaluation

Cased hole lithology, TOC and formation sigma used to improve open hole interpretation

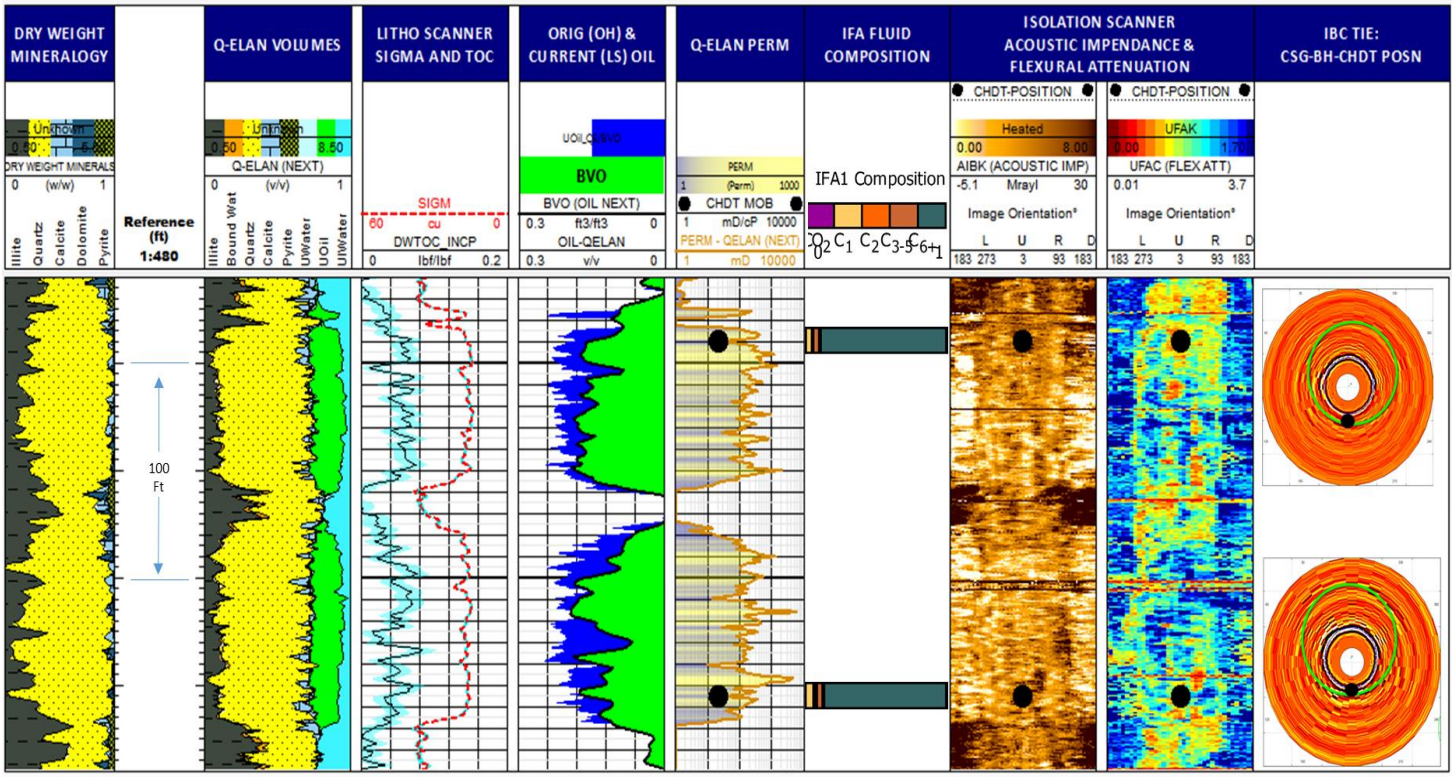


- High definition spectroscopy identifies a gas zone which was by-passes by conventional logs
- Elemental concentrations of potassium, calcium and sodium enables advanced mineralogy such as feldspar content in main reservoir intervals.

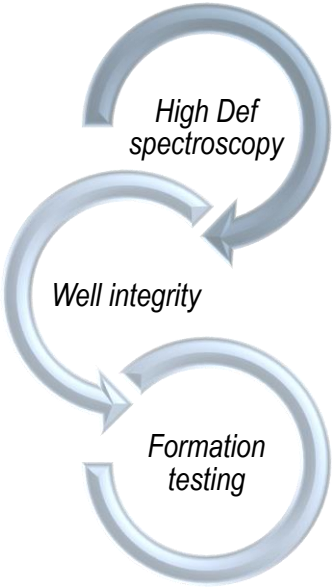
Mineralogy & Fluids in Difficult Conditions

Integrated approach for collecting new data in existing old wells

- Mitigating drilling risk
- Taking advantage of new technology to collect data in large casing and borehole
- Leading to successful holes plugging

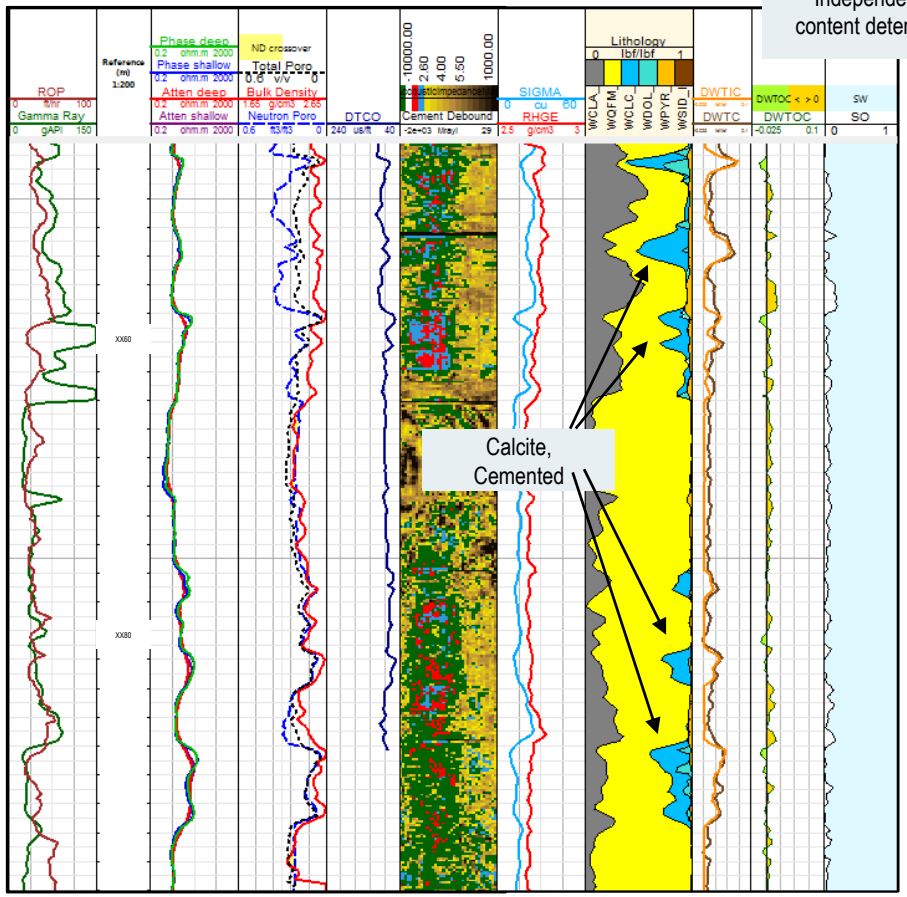


Large 11.875" casing; in front of 14.5" bit size



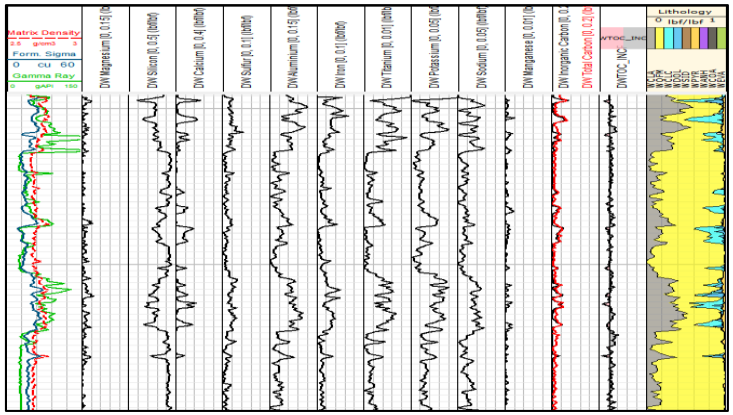
- Critical present day oil saturation from TOC
- FSAL estimate from Sigma, also shedding light on the complex reservoir environment

Enabling Critical Decision Making



- Complex Turonian player
- LWD resistivity combined to cased hole neutron-density is inconclusive

- High definition Spectroscopy solves for Quantitative mineralogy, clays, matrix density for corrected porosity, rock quality and variations as well as fluids content.



- Accurate fast carbon content for correct saturation and reserves estimate.
- The confident results enabled informed and fast decision making for FDP

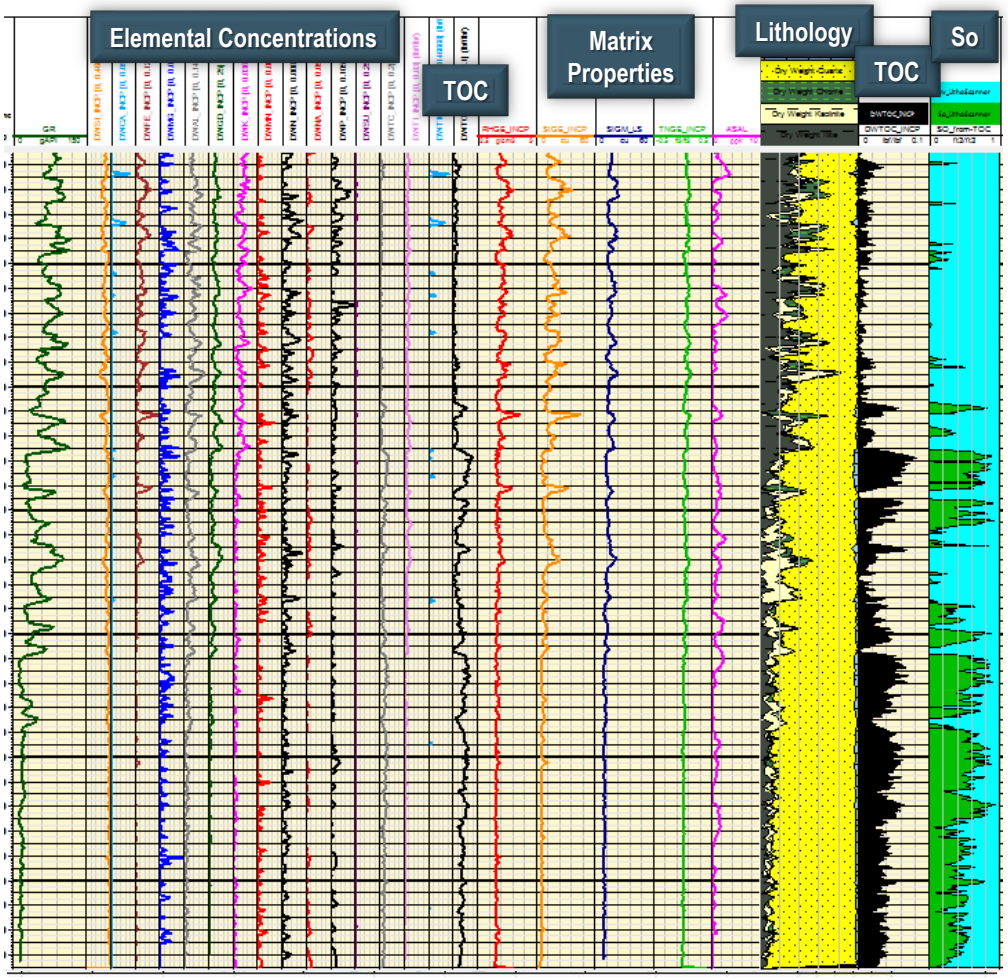
Adding Operational Efficiency

Saturation requires both Sigma and Carbon/Oxygen logging

Interest zone = 800ft

- Standard Pulse Neutron acquisition
  - 1 Sigma pass at 1500 ft/h (~ 30 min)
  - 3 CO passes at 100 ft/h each (~ 24hs - 8hs x pass)

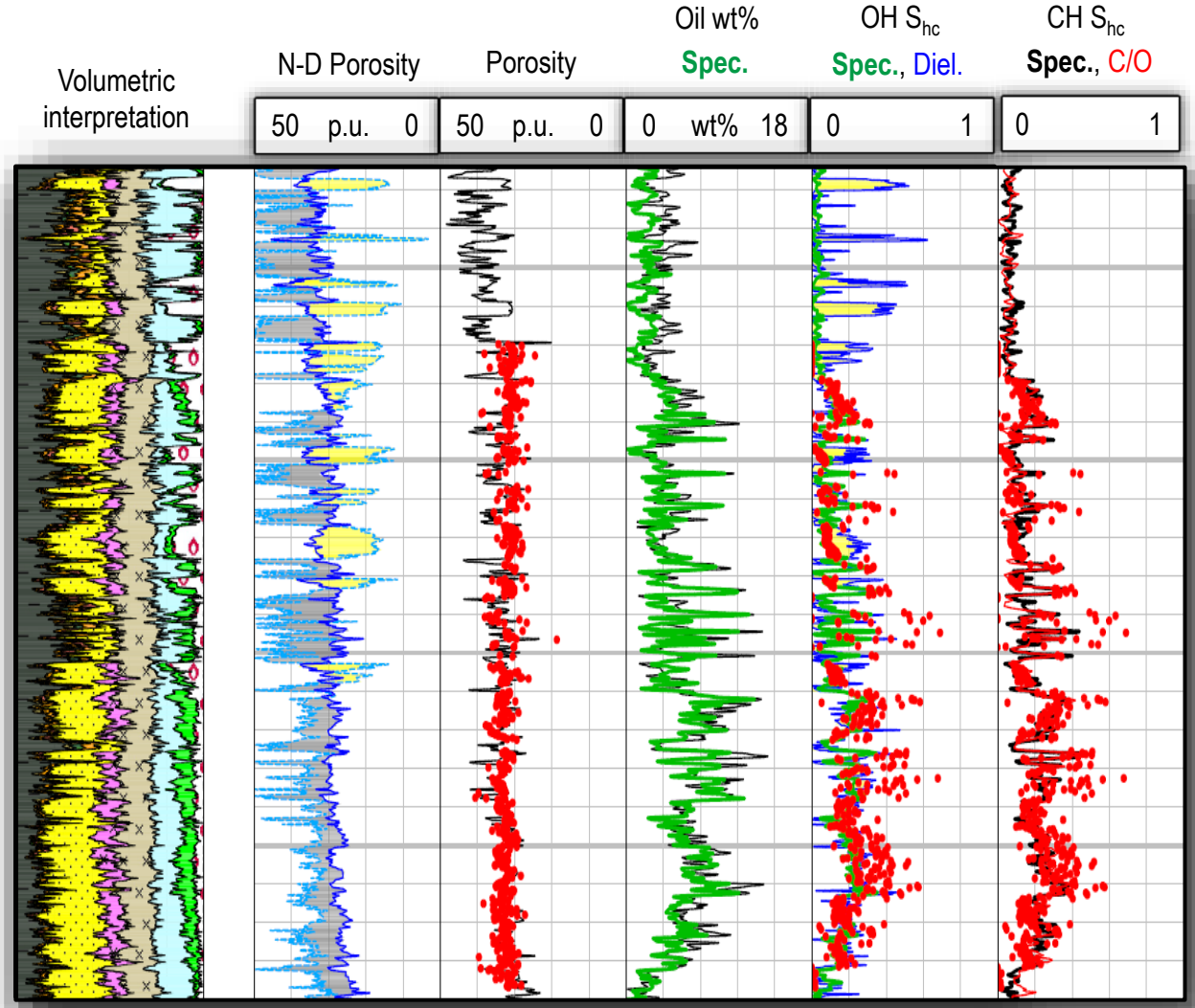
- New Spectroscopy acquisition
  - 1 Sigma + Spectroscopy pass at 500 ft/h (~ 90 min)
  - 1 short repeat pass (~ 20 min)



Ref.: SPE-1777095, 2015, U. Bustos et al.

Remaining Oil Saturation

Heavy oil sandstone under EOR



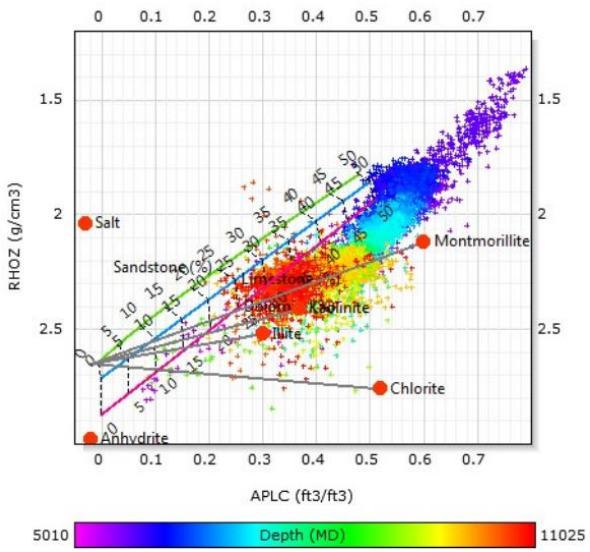
- Evaluation challenges
  - Resistivity-based estimate of residual oil saturation fails
  - Variable salinity and temp. from steam injection
  - Complex mineralogy
- Solution
  - Measure carbon yield independently with high definition spectroscopy in efficient logging
- Results
  - Direct Oil Volume from carbon weight % (TOC) in open- and cased-hole; matching cores
  - Rig time saving and enhanced precision compared to std PNL

Ref.: SPE-166297, 2013, P.R. Craddock et al.

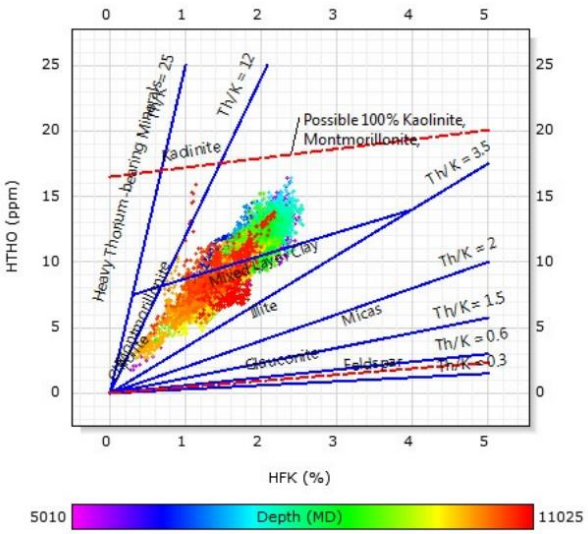
Guide to Sustainable Production & Abandonment

North Sea example

- Mature field, variable rock strength and pressure, sealing, fractures, compaction
- Complex lithological system: organic matter, clay typing, iron-rich content, free-gas volumes, carbonate stringent
- Swelling clays as permanent annular barrier during P&A is often uncertain due to heterogeneity, variable geomechanics



- Overburden characterization is critical
- Conventional methods fails and coring large sections of the overburden is problematic
- A new approach using high-definition spectroscopy unveil overburden properties for prompt decision making



Ref.: SPWLA 56th Annual Symposium, A. Chatterjee et al.

Solving the Lithology Enigma

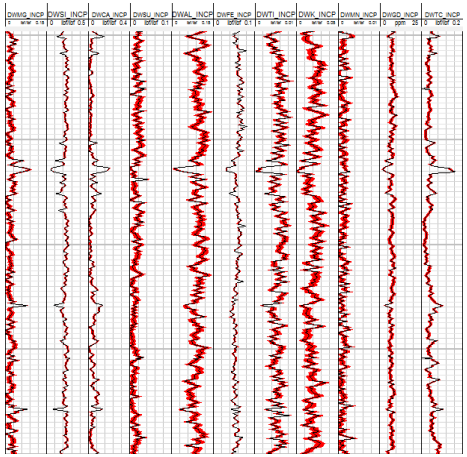
Overburden section of swelling clay, high Kerogen, high porosity and gas saturation

Spectroscopy analysis, TOC, sigma processing

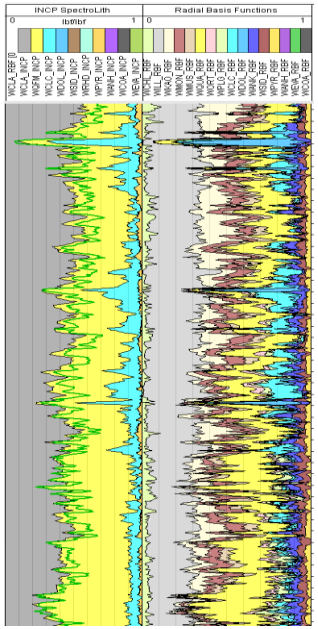
Oxide closure: dry weights to minerals

4 clay types observed

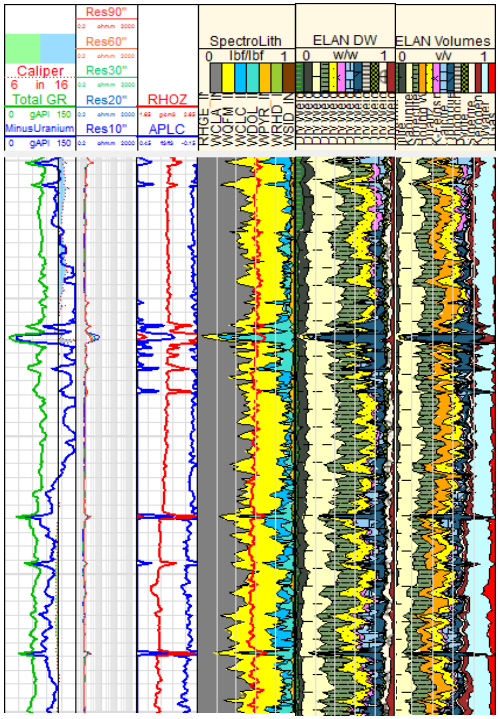
15 components multi-mineral solver from DW integrated to clays % from offset well



Large suite of rock forming Elemental DW, minimal measurement uncertainties

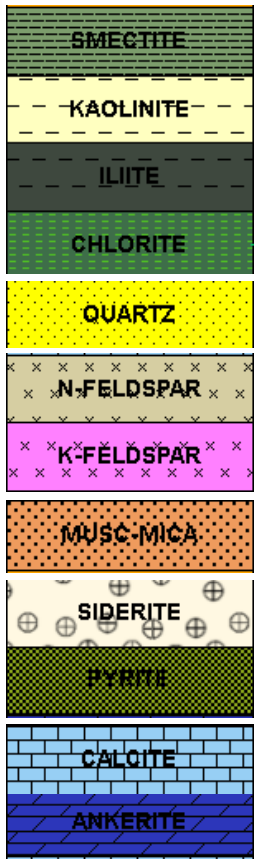


Guide to integrated answer

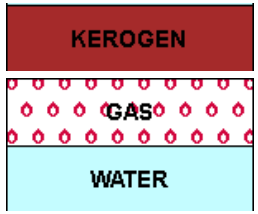


Spectroscopy **(Al, Si, Fe, Ca, Mg, Mn, S, Ti, Gd, K, Na, C) – (12)**
Density, Porosity (2); Resistivity (1); Spectral GR (3); Sonic (2)

12 Minerals



Kerogen, 2 Fluids



Ref.: SPWLA 56th Annual Symposium, A. Chatterjee et al.

Conclusions

- The New Generation High-Definition Spectroscopy measurement provides new information on rock properties and fluid distribution for reservoir management.
- Clays typing, In-situ Organic Carbon (TOC) for hydrocarbon quantification, and Formation Sigma also available
- The ability to determine both the matrix mineral composition and total organic carbon (TOC) are instrumental to the geoscientist, the petrophysicist, the reservoir engineer, and also the completion engineer.

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