Novel Approach for Improved Evaluation and Saturation Estimate Behind Casing of the Gotnia Formation Using New Advanced Inelastic and Capture Nuclear Spectroscopy Technique*

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Abstract

The Gotnia Formation is comprised of alternating halite and anhydrite with limestone intercalations, and is traditionally considered a regional seal for Lower Jurassic hydrocarbon bearing reservoirs. The sharp contrast in lithology of halite-anhydrite and high pressure in interbedded limestone layers make this formation extremely challenging to drill and evaluate. Casing is set immediately after drilling, limiting openhole data acquisition. Due to complex lithology and low porosity, a comprehensive acquisition and interpretation methodology was required to further characterize and assess the potential of this formation. Recent hydrocarbon discovery over these formations has opened up new limits for exploration and enabled new characterization techniques for evaluation behind casing.

The technique provides a robust and accurate total organic carbon (TOC) estimate, taking advantage of the recent advances on the inelastic and capture gamma-ray spectroscopy measurements of the pulsed neutron logging tool. It differs from the well-known approach of using carbon-to-oxygen ratios that is most often applied in cased-hole evaluation. The main advantages of this new method are that it does not require knowledge of formation water resistivity, it does not rely on a resistivity model, it does not require an extensive calibration database, and it is largely independent of the lithology effects.

The petrophysical interpretation consists of first computing element dry-weight fractions from which the lithology of the Gotnia units and their alternating halite and anhydrite layers are derived. The novel approach uses the directly measured TOC to estimate hydrocarbon saturation. The inorganic carbon in limestone within Gotnia units is estimated by using the elements from this logging tool (Ca, Mg, Mn, and Fe) and the value is subtracted from the measured total carbon to give TOC from which the hydrocarbon saturation is derived. The logging parameters applied to the logged Gotnia interval are optimized to minimize uncertainties and the precisions on the TOC which is around 0.5-1.0 wt %. The saturation derived using this method was compared to the offset wells' evaluation with a very good agreement. The technique has provided a safe and practical solution for a comprehensive evaluation and saturation estimate of the Gotnia Formation, shedding the light on its reservoir potential.

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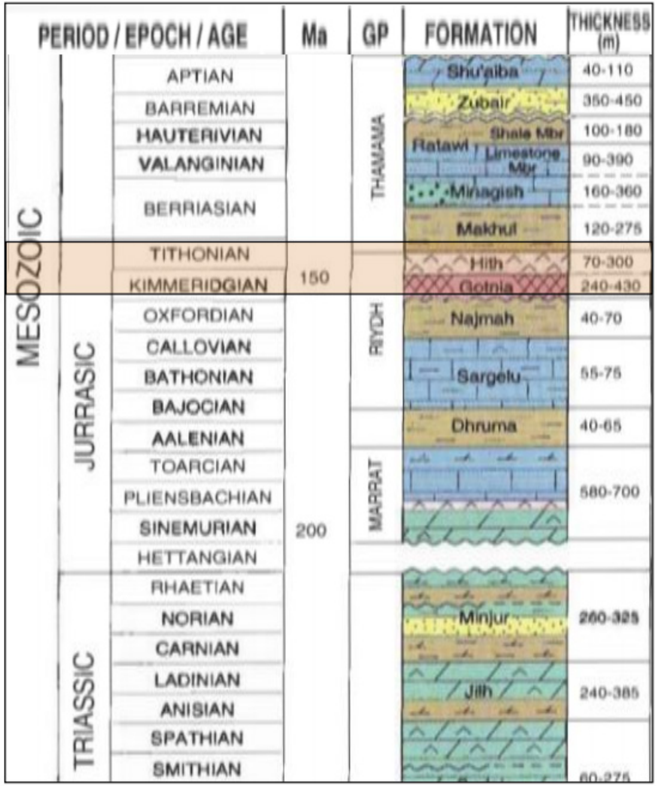
Outline

- Evaluation Challenges and Objectives
- New Spectroscopy Technology – Brief Description
- Saturation Derivation – New Technique
- Case Study-Kuwait
- Conclusions

Hith-Gotnia Evaluation Challenges

- Hith formation consists of anhydrite interbedded with limestone and some shale while the Gotnia formation, underlying the former, is a massive salt-anhydrite sequence with pore pressure approaching overburden gradient.
- Logging while drilling, wireline and core data acquisition is very challenging because of the high pressured and harsh environment
- Both formations are traditionally overlooked as potential reservoirs because of the limited data acquisition in high-pressured environment.
- Behind casing evaluation has been identified as a solution to characterize these formations and unlock these reservoirs



Evaluation Objectives

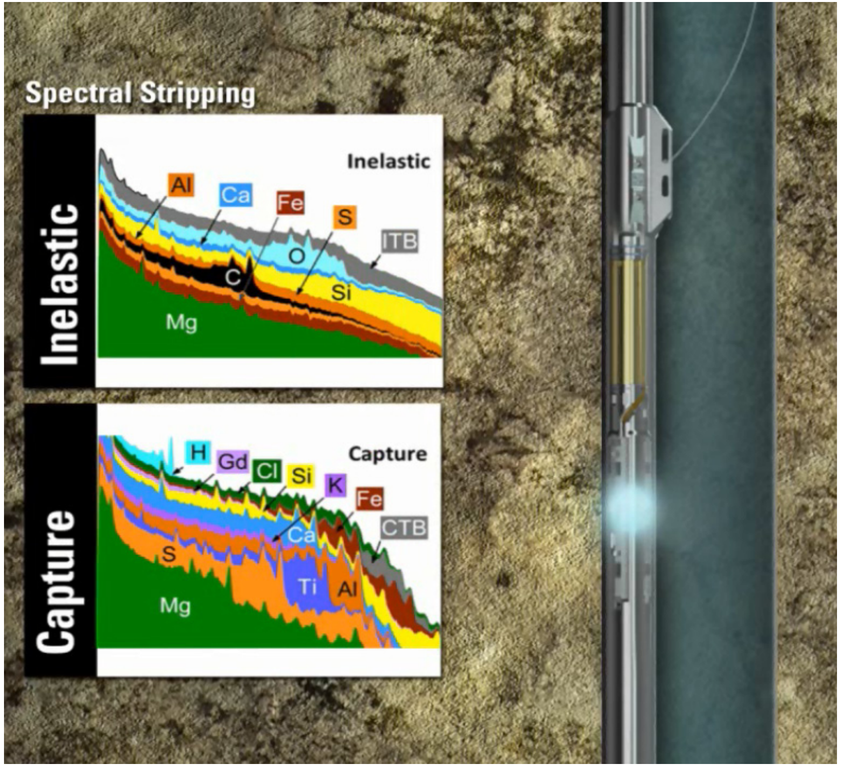
- Logging Data:
  - Advanced spectroscopy measurement
  - Elemental and mineral dry weights
  - Total organic content for direct HC saturation estimate
  - Cover the limited open hole logs
- Core and cuttings Data:
  - Elemental (XRD/XRF) cuttings analysis
  - No core

Paper Objectives:

- Comprehensive evaluation of carbonates behind casing
- Validate the log data behind casing using the XRF & XRD on cutting:
  - Elemental data
  - Mineralogical data
- Estimate hydrocarbon saturation from the measured in-situ TOC

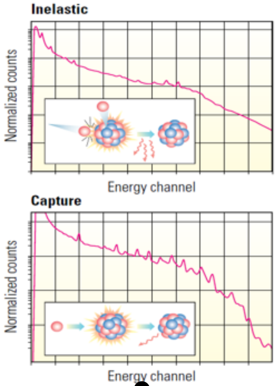
New Spectroscopy Technique - Introduction

- In-situ Total Organic Carbon (TOC)
- Enhanced suite of elements for complex reservoirs.

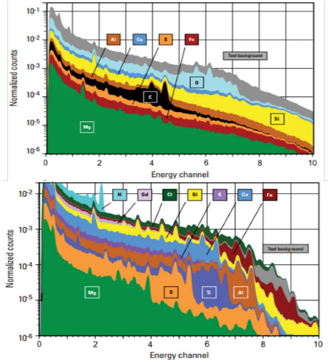


Interpretation Workflow

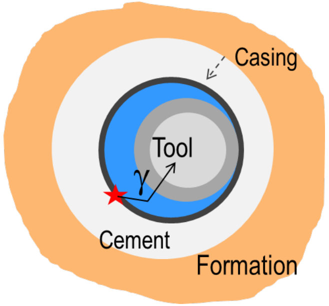
Spectral acquisition, spectral stripping → Cased hole processing, Oxide closure → Reservoir parameters, Interpretation



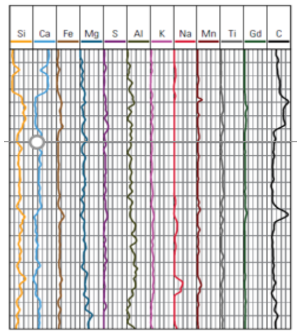
Spectra



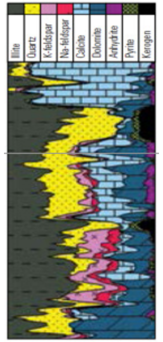
Elemental Yields



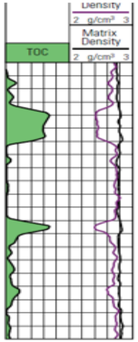
Spectral reconstruction, cased hole correction



Dry Weight Elements



Mineralogy



TOC for HC Saturation

Hydrocarbon Saturation From TOC – Direct Approach

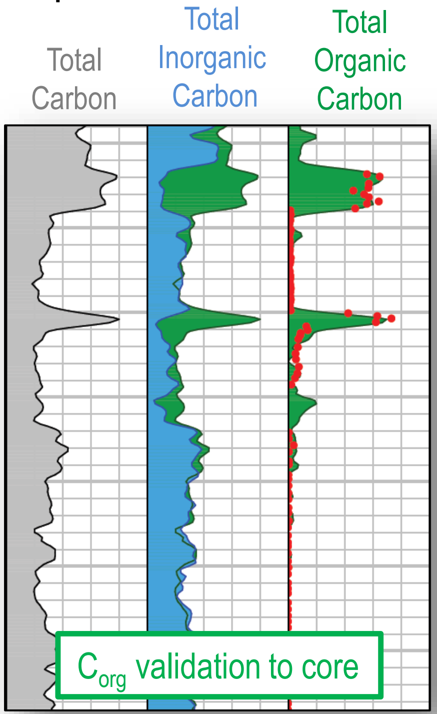
- Objective hydrocarbon saturation from the new spectroscopy technique
  - Independent of formation water salinity
  - Independent of the Archie' parameters

Spectroscopy measurement

External Input from OH

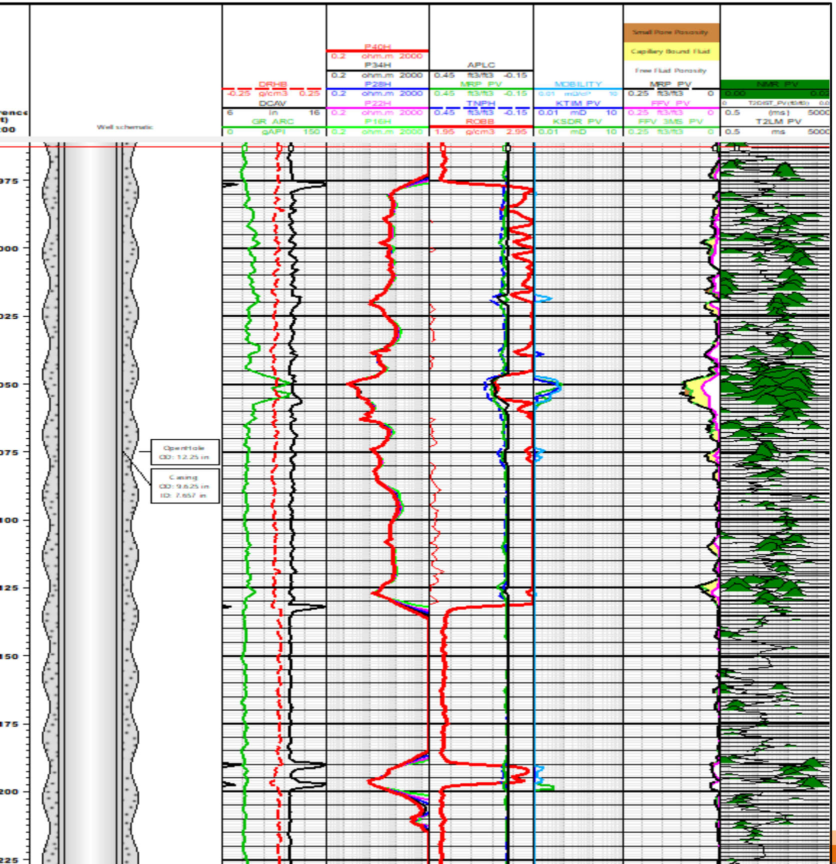
$$S_{hc} = \frac{TOC \cdot \rho_{ma} \cdot (1-\phi_T)}{\rho_{hc} \cdot X_{hc} \cdot \phi_T}$$

External Input



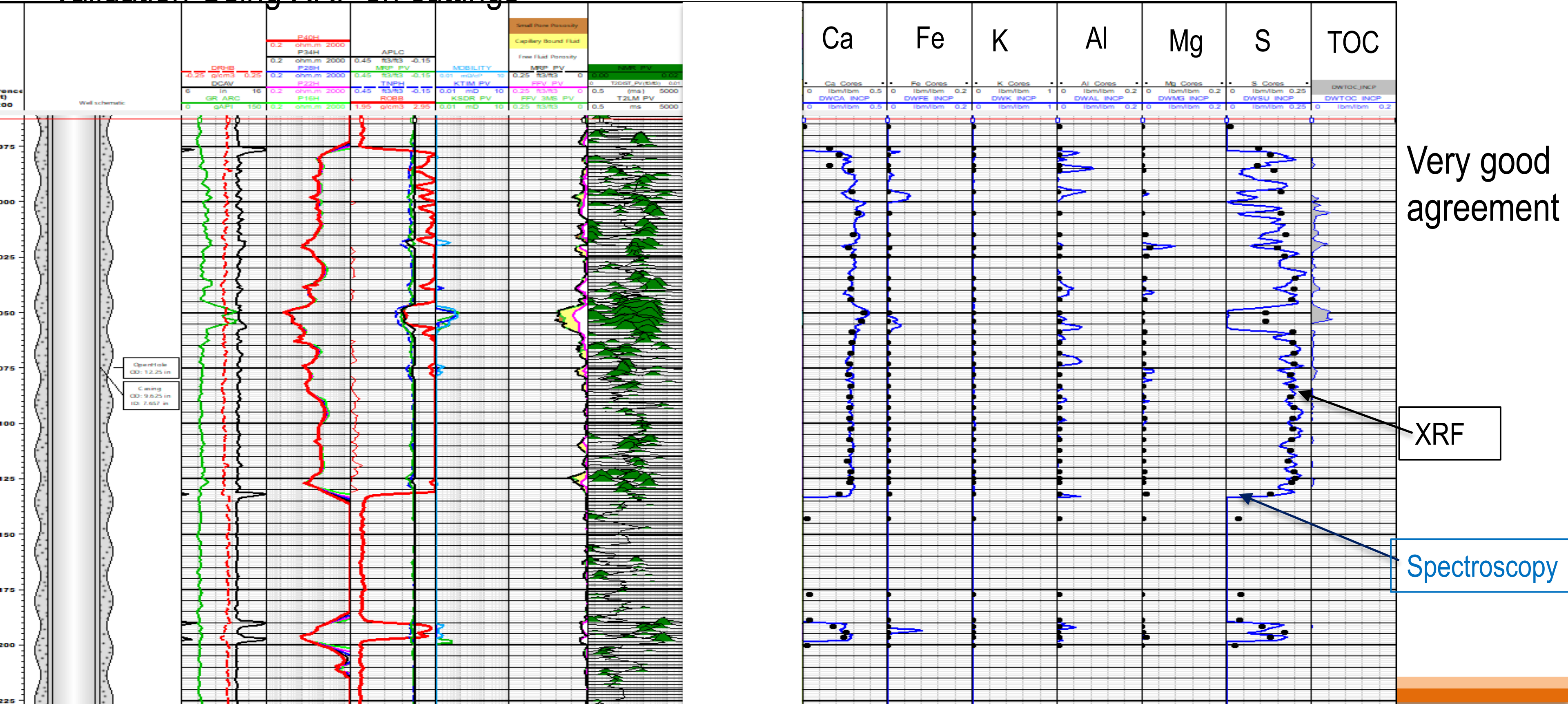
- TOC, ρ_{ma} = TOC, matrix density from advanced spectroscopy log
- ϕ_T = porosity from Neutron-Density matrix-corrected using ρ_{ma} log
- X_{hc} = carbon fraction of oil (assigned)
- ρ_{hc} = oil density (assigned, light oil ~0.5-0.85 gm/cc; bitumen ~ 1.01-1.05 gm/cc)

Case Study: Initial Interpretation of Gotnia Formation Using OH data

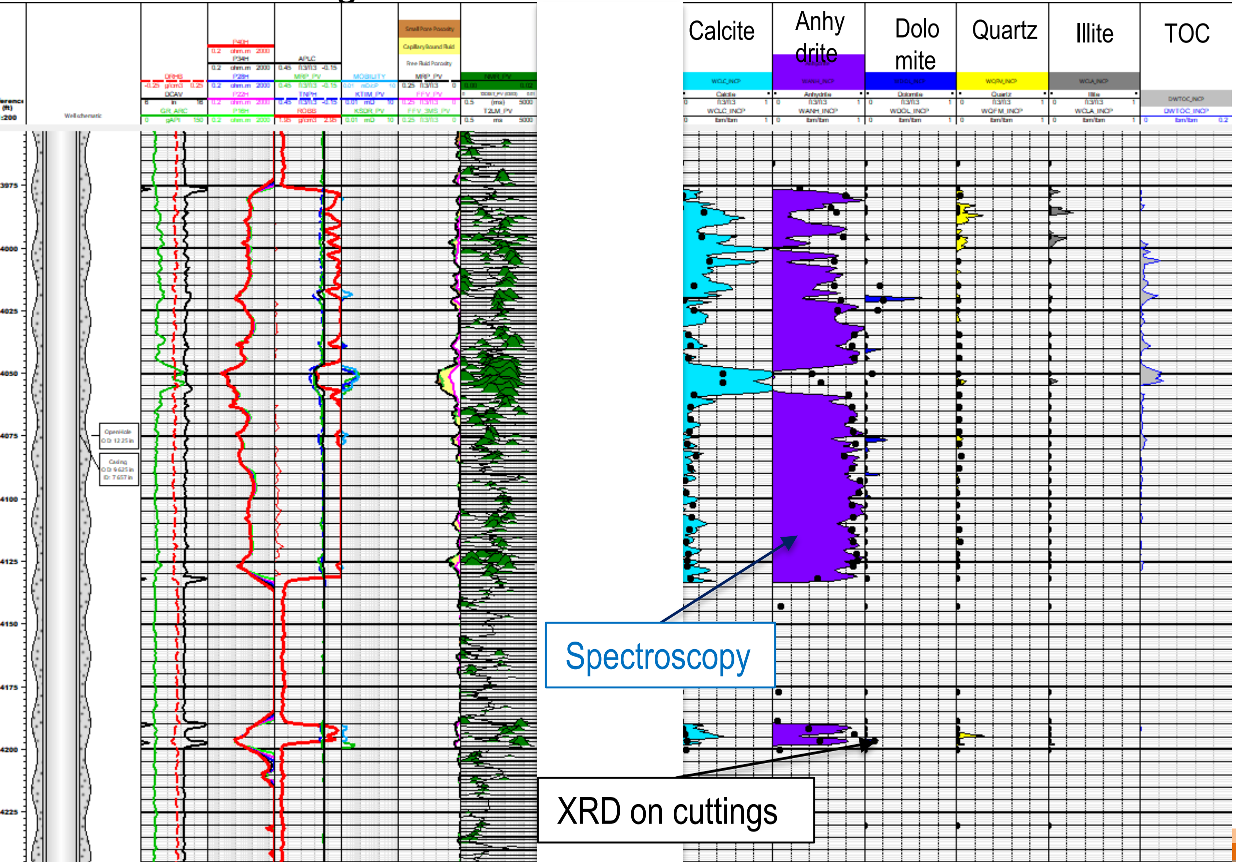


- Basic logging along with NMR were recorded while drilling.
- Comprehensive lithology was missing over the logged section

Dry Weight Measurements using the New Spectroscopy Logging Behind Casing – Validation Using XRF on cuttings -

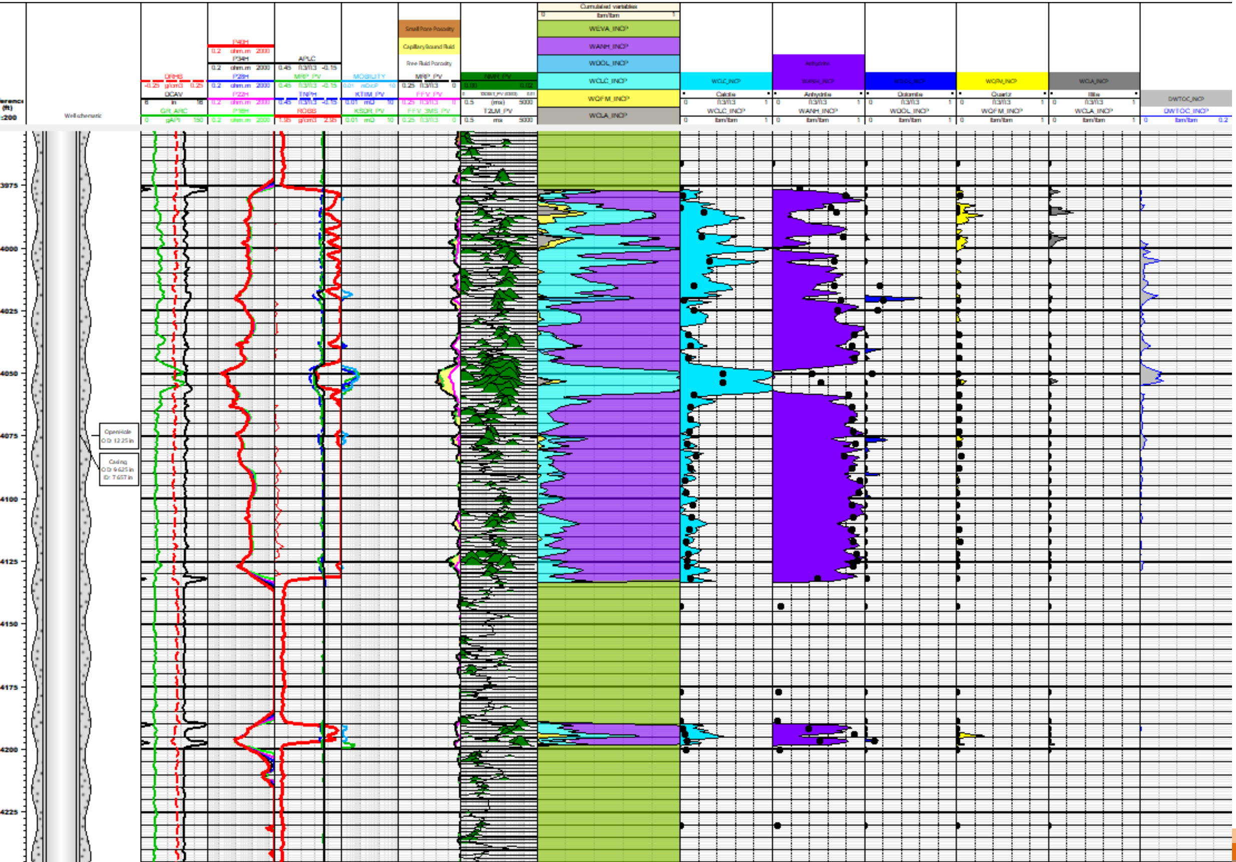


Mineralogy Measurements using the New Spectroscopy Logging Behind Casing – Validation Using XRD



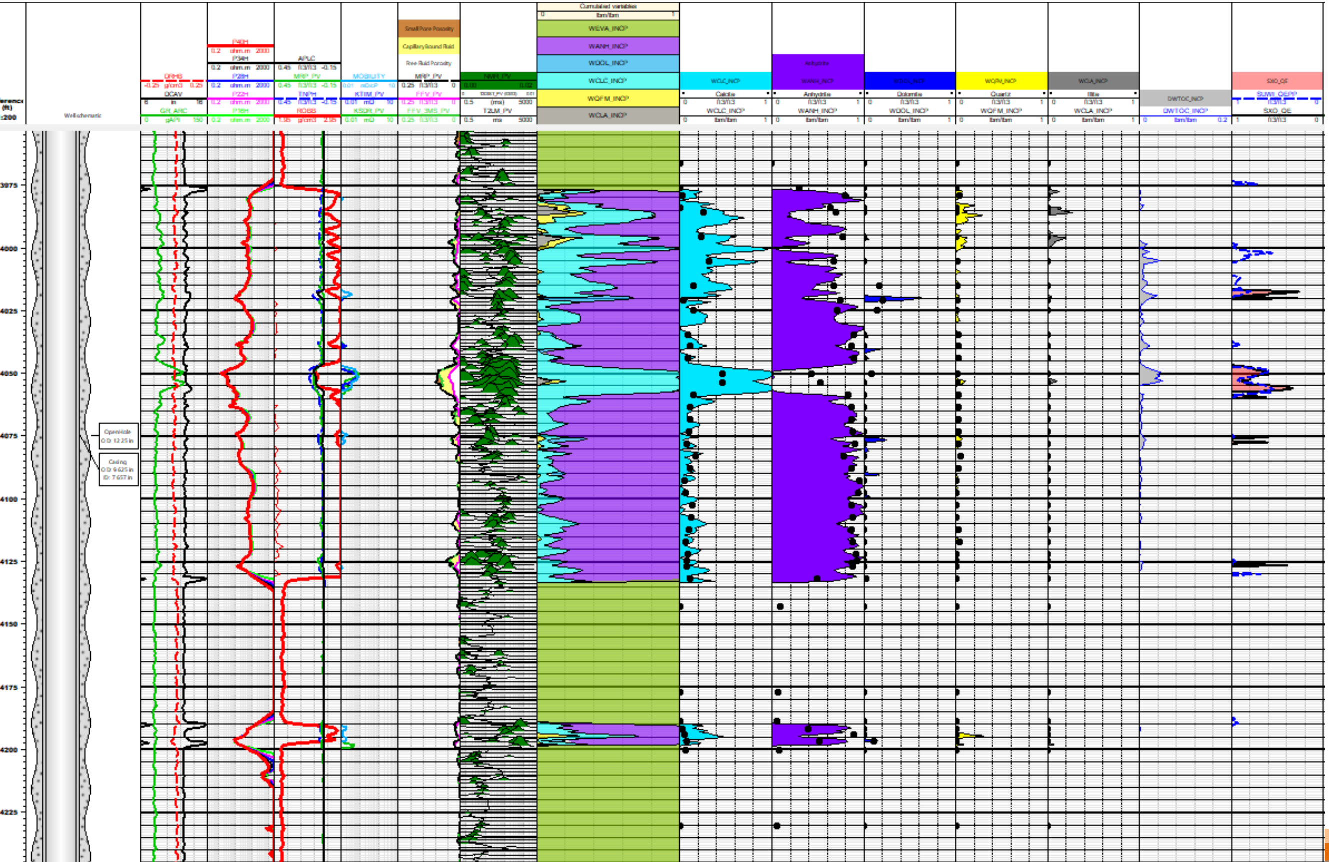
- Very good agreement between the lithology weight percentage from the new spectroscopy tool and XRD measurements on cutting.
- Spectroscopy technology is showing higher resolution measurements

Lithology Evaluation Behind Casing of Gotnia Formation



- Comprehensive lithology evaluation behind casing
- Spectroscopy technology is showing higher resolution measurements

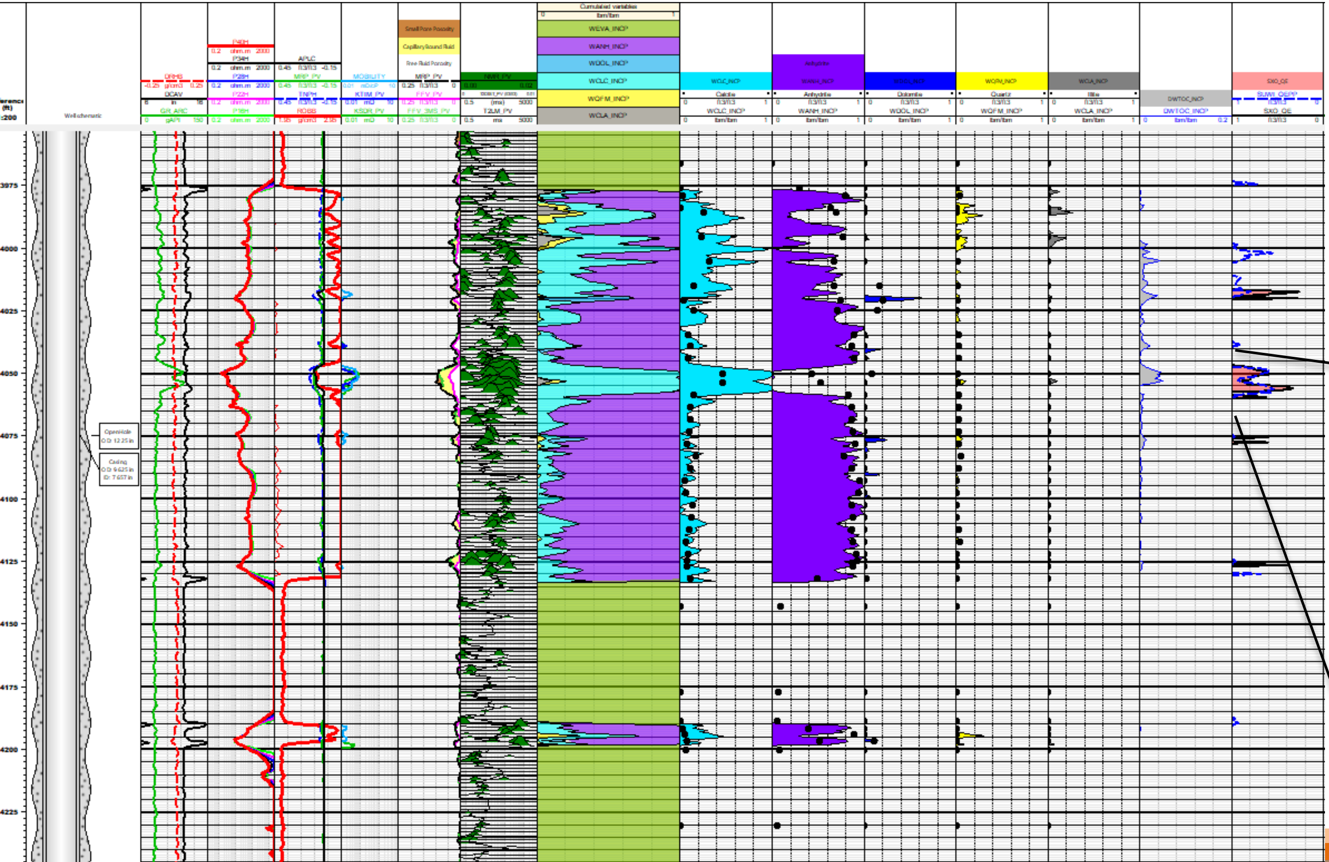
Saturation Evaluation Using the New Spectroscopy – Direct Approach



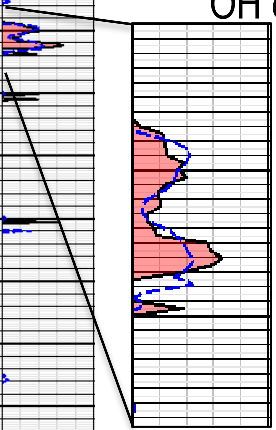
Direct Saturation estimate using the TOC from the new spectroscopy measurement

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

Saturation Evaluation Using the New Spectroscopy – Direct Approach



- Direct Saturation estimate using the TOC from the new spectroscopy measurement
- Direct saturation estimate is in a very good agreement to OH evaluation



Conclusions

- Comprehensive lithology evaluation behind casing has been demonstrated by the new advanced spectroscopy measurements over the very challenging Carbonate Hith-Gotnia formations.

- The dry weight elements and mineralogy over the logged Hith-Gotnia formation were validated using the XRD ad XRF analysis on cuttings. Very good agreement has been demonstrated.

- The new advanced technology has also provided a standalone evaluation of direct saturation estimate which was also in agreement with OH saturation evaluation

- The new advanced spectroscopy logging behind casing was well integrated with LWD data and provided a comprehensive reservoir evaluation.