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Petrophysical and geochemical interpretations of well logs from the pre-Carboniferous succession in Barnicarndy 1, Canning Basin, Western Australia

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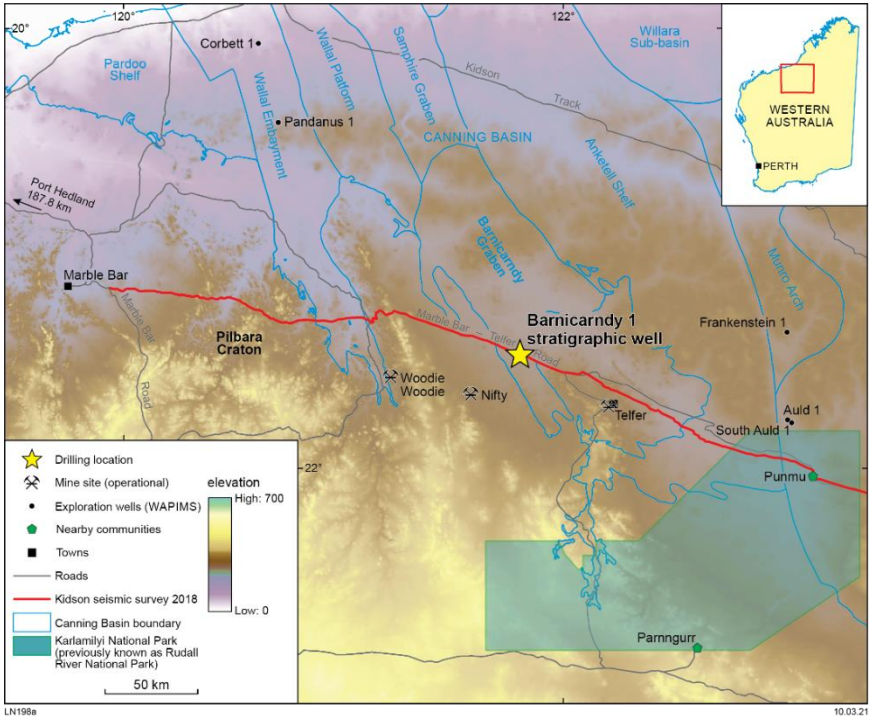
Petrophysical and geochemical interpretations in Barnicarndy 1

1) Introduction
2) Conventional interpretation
3) Petrophysical interpretation using artificial neural network technology
4) Thermal maturity and hydrocarbon generation
5) Conclusion

Barnicarndy 1

- Barnicarndy 1 is a stratigraphic well drilled in the southern part of the Canning Basin's Barnicarndy Graben.
- Under Geoscience Australia's Exploring for the Future (EFTF) program in collaboration with the Geological Survey of Western Australia (GSWA).
- To provide stratigraphic data for the poorly understood tectonic component – Barnicarndy Graben.
- Total depth: 2680.53 m (driller's).
- The well intersects a thin Cenozoic section, overlying Permian–Carboniferous fluvial clastics and glacial diamictites, with a thick pre-Carboniferous succession (855–2585 mRT) unconformably overlying the Neoproterozoic metasediments.



Location of the Barnicarndy1 well on the Kidson seismic line (18GA-KB1, red curve) in the Barnicarndy Graben of the southwest Canning Basin (Normore and Rapaic, 2020)

Data availability

- **Well logs (WAPIMS):**
  - Well logging data were acquired by Wireline Services Group (WSG) above 1602.8 mRT and by Weatherford Logging to the total depth.

- **Laboratory measurements:**
  - Routine core analysis (radioactive spectroscopy, porperm, etc.)
  - Geomechanical properties
  - FIS, ICP, XRD, RockEval, thermal maturity

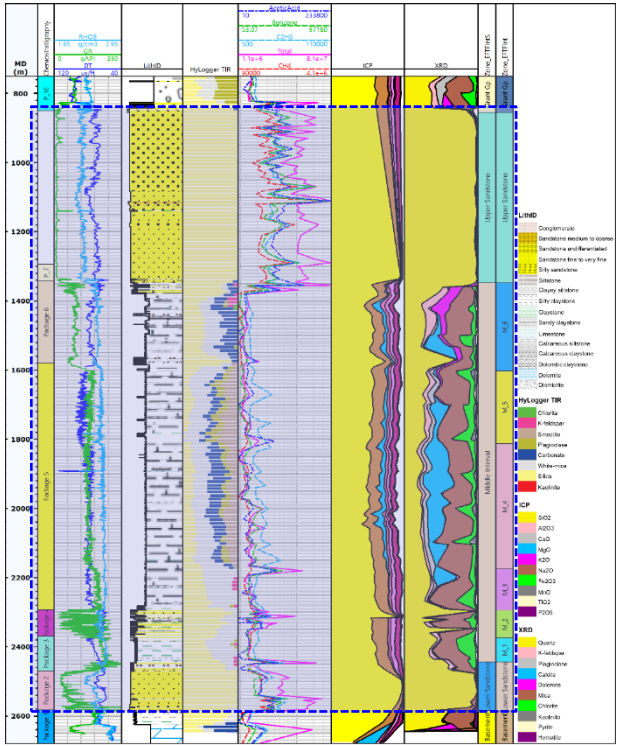
Well log interpretation in Barnicarndy 1

1) Conventional interpretation:
    - Effective porosity, water saturation and dynamic elastic properties
2) Artificial neural network application:
    - Total organic carbon content (TOC, wt%)
    - Pyrolysis products from the cracking of organic matter (S2, mg HC/g Rock)
    - Permeability
    - Mineral compositions
3) 855-2585 mRT
4) Techlog-Schlumberger platform

Definition of internal intervals

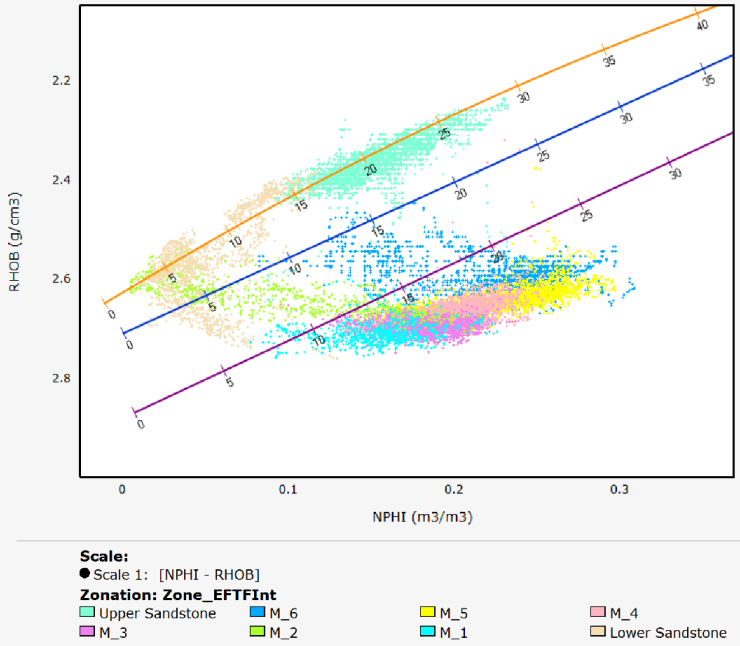
Interpretation intervals/zones at Barnicarndy 1

First order zones (Zone_EFTFIntS)	Second order zones (Zone_EFTFInt)	Top depth (mRT)	Bottom depth (mRT)
Grant Group	Grant Group	96	855
Upper Sandstone	Upper Sandstone	855	1348.1
Middle Interval	M_6	1348.1	1602.6
	M_5	1602.6	1813.1
	M_4	1813.1	2175.7
	M_3	2175.7	2293.7
	M_2	2293.7	2374.7
	M_1	2374.7	2443.4
Lower Sandstone	Lower Sandstone	2443.4	2585
Basement	Basement	2585	2680



Interpretation intervals/zones at Barnicarndy 1

Neutron-Density crossplot and effective porosity



Neutron-Density crossplot in Barnicarndy 1

Effective porosity at Barnicarndy 1

Zones	PHIE_ND (fraction)	PHIE_NDsh (fraction)
Upper Sandstone	**0.179**	0.066
M_6	0.063	0.060
M_5	0.056	0.055
M_4	0.032	0.032
M_3	0.023	0.022
M_2	0.044	0.046
M_1	0.025	0.025
Middle Interval	0.043	**0.042**
Lower Sandstone	**0.067**	0.005

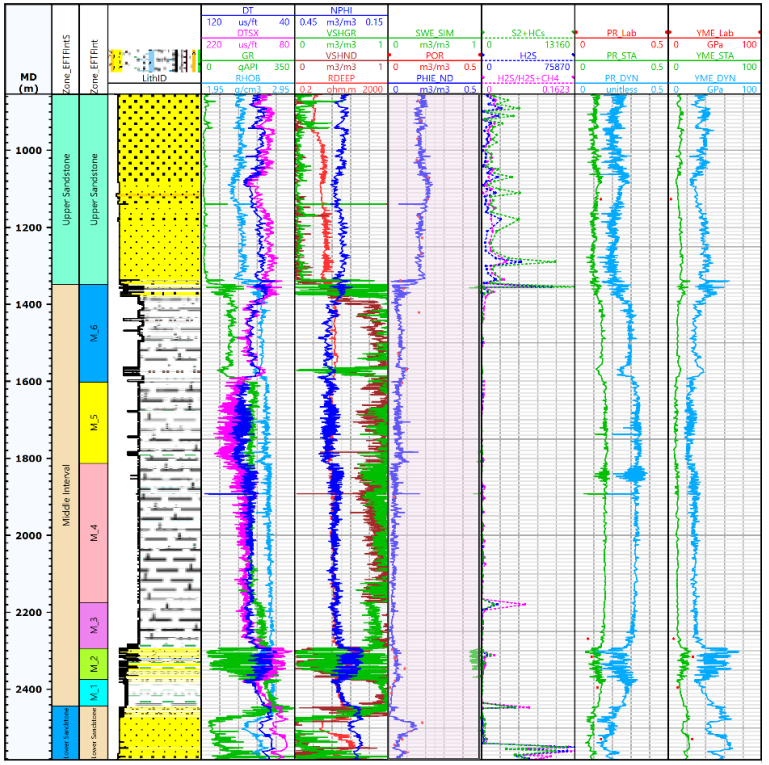
Water saturation

Fluid inclusion stratigraphy (FIS):

- Sulfur species are sporadically present in most of the sandstone intervals.
- Generally associated with water-bearing, porous reservoir rocks. Hence the water saturation in the Upper Sandstone is 1.0 (fraction).

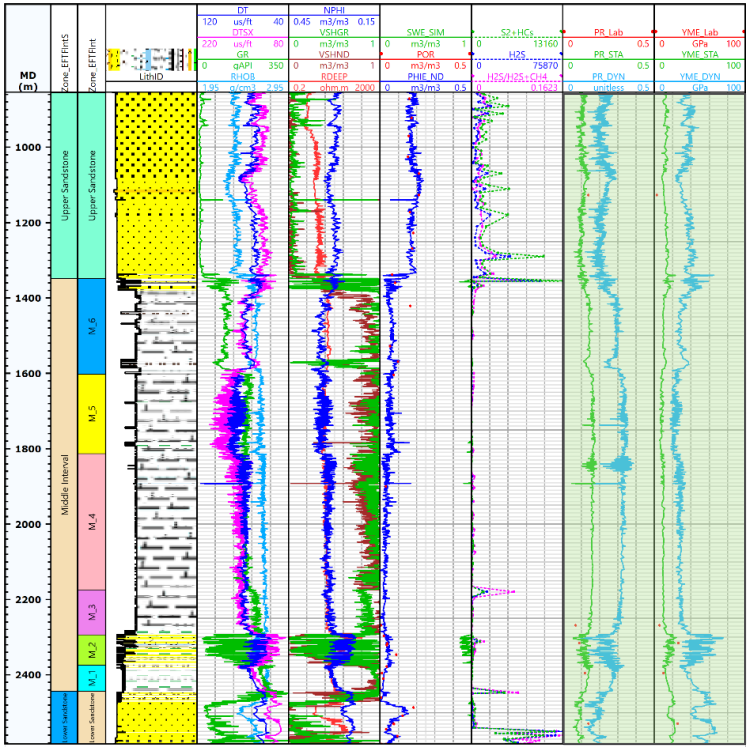
Simandeux equation:

$$\frac{\emptyset_e^m}{a \times Rw} \times S_w^n + \frac{V_{sh}}{R_{sh}} \times S_w - \frac{1}{R_t} = 0$$



Conventional interpretation results at Barnicarndy 1

Elastic properties



Conventional interpretation results at Barnicarndy 1

Interpreted static elastic properties at Barnicarndy 1

Rock type	Interval	Average Poisson's ratio (fraction)	Average Young's modulus (GPa)
Sandstone	Upper Sandstone	0.107	12.33
	Middle Interval	0.113	16.42
	Lower Sandstone	0.091	18.99
	All sandstones	**0.105**	**14.18**
Claystone	Middle Interval	**0.154**	**9.81**

Artificial neural network

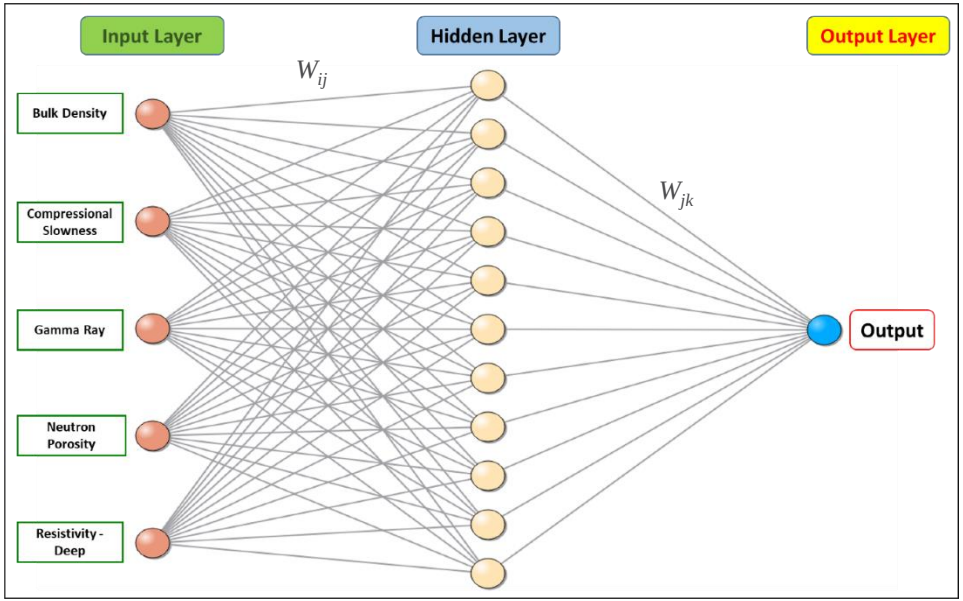
Artificial neural network has been applied in estimating the laboratory measurements, from geophysical logs.

Conventional interpretation:

- Inputs → interpretation method → outputs
- eg. sonic slowness→Willie's equation→porosity

Artificial neural network:

- Multi-layer perceptron (MLP)
- Step 1: Training patterns (inputs and output/target) → trained neural network model
- Step 2: Inputs → trained model →outputs



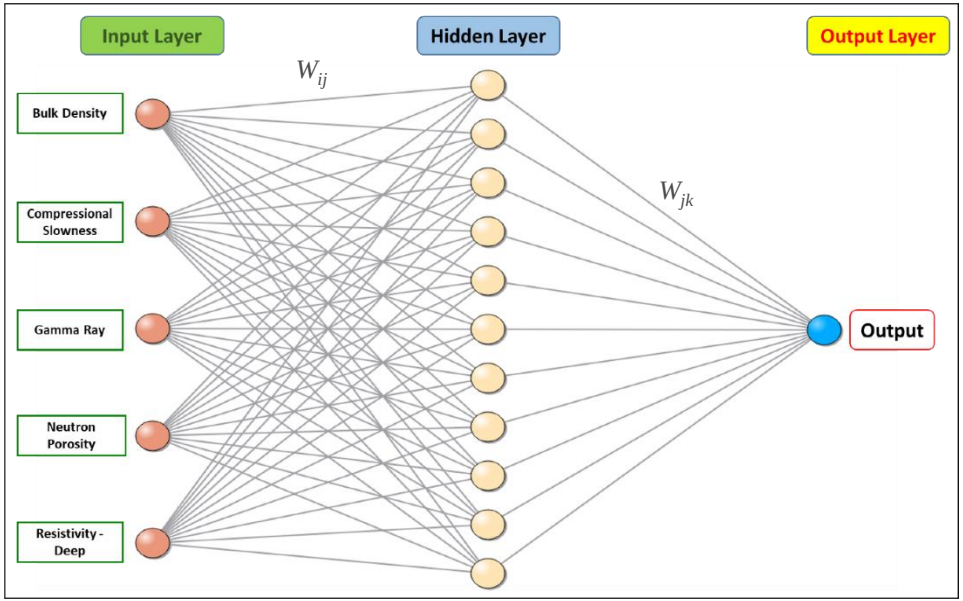
Artificial neural network (MLP) architecture with multiple inputs and one output.

Artificial neural network - applications

Training pattern:

- Input parameters:
  - bulk density (RHOB, g/cm^3)
  - compressional wave slowness (DT, μs/ft)
  - gamma ray (GR, gAPI)
  - neutron porosity (NPHI, m^3/m^3)
  - deep resistivity (RDEEP, ohmm)

- Output parameter:
  - TOC and S2
  - Permeability
  - Mineral compositions

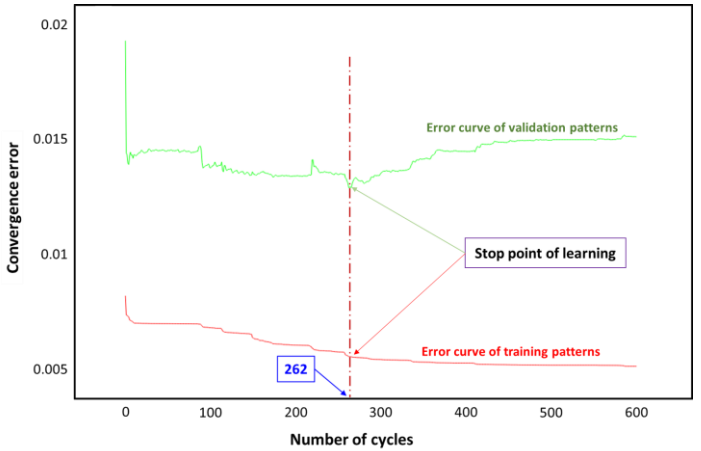


Multi-layer neural network architecture with multiple inputs and one output.

TOC and S2 interpretation

- Total organic carbon (TOC) content indicates the richness of organic matter in sedimentary rocks.

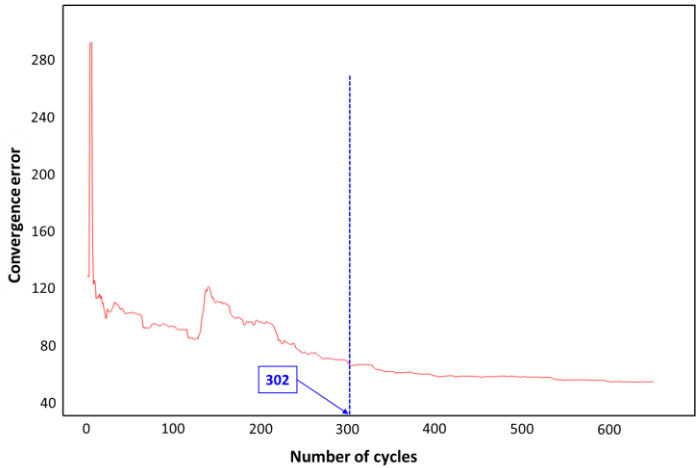
- 199 samples from Barnicarndy 1 were analysed on a Rock-Eval 6 instrument.
  - TOC (wt%)
  - S2 (mg HC/g rock).
- Validation training – early stopping:
  - Training: 170 patterns
  - Validation: 29 patterns



Error curves during TOC interpretation.

Permeability interpretation

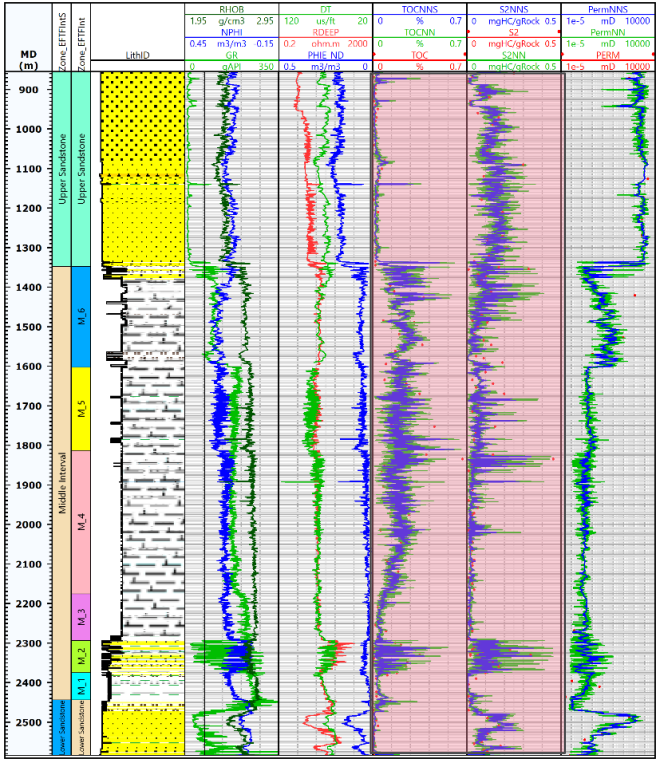
- 38 laboratory measured permeabilities on samples from Barnicarndy 1
- Output parameter:
  - Permeability



Error curves during permeability interpretation.

Neural network interpretation results

- The estimations and laboratory measurements are highly correlated.
- Maximum TOC and S2 in the Middle Interval claystone are 0.66 wt% and 0.46 mg HC/g Rock, respectively.
- Geometric mean reservoir permeability is 464.5 mD and 10 mD respectively in the Upper and Lower Sandstone intervals.

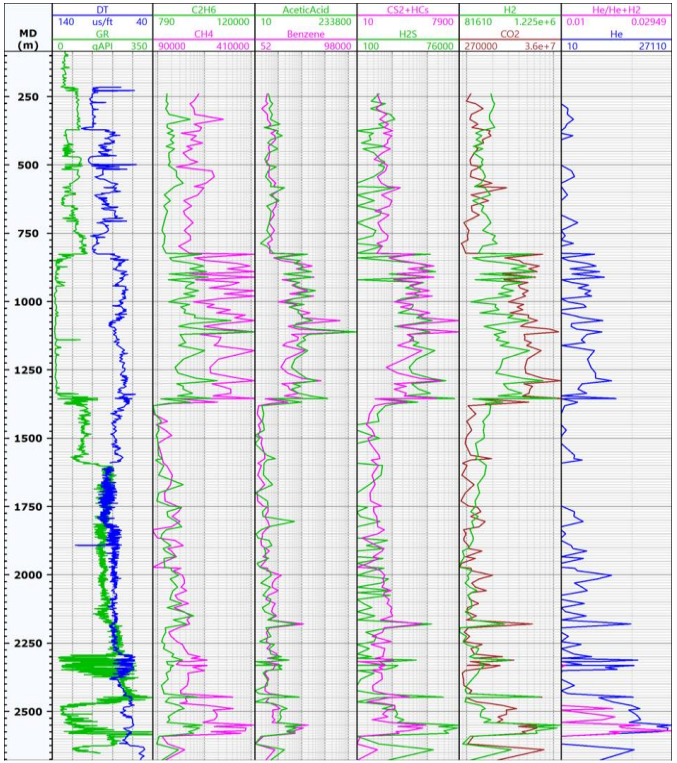


TOC, S2 and permeability interpretations in Barnicarndy 1.

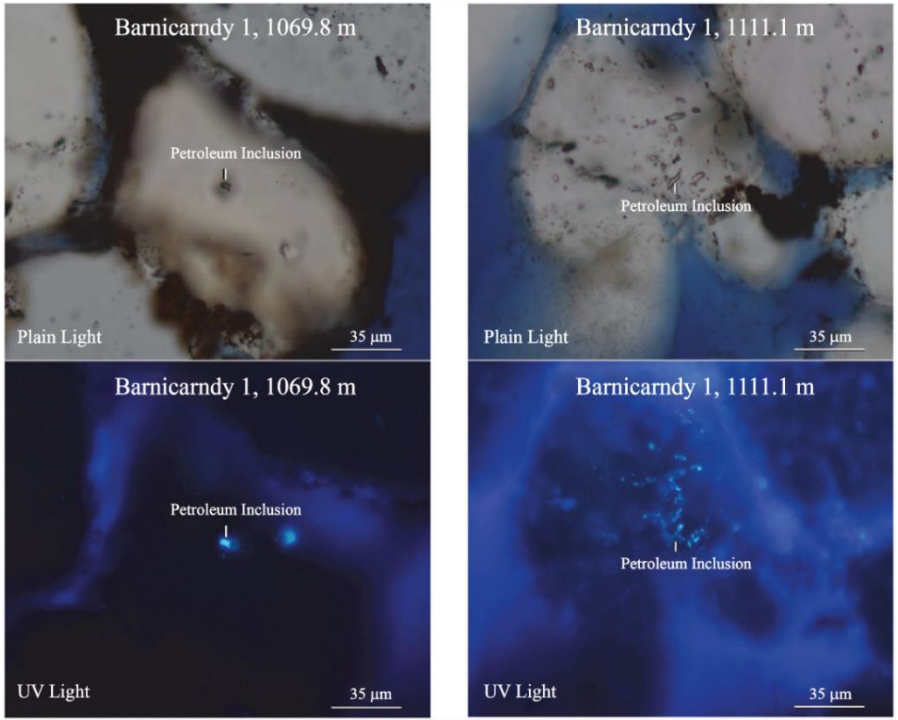
Thermal maturity

- **Eleven samples** from the depth range of 1354.8–2244.08 mRT were tested to obtain **graptolite reflectance** due to the lack of vitrinite in the target interval.
- The mean of maximum graptolite reflectance ranges from **0.83% to 2%**, and was converted to vitrinite reflectance using the transformation as ($EqVRo = 0.515 \times GRomax + 0.506$) (Luo et al. 2020).
- The calculated equivalent vitrinite reflectance (EqVRo, %) ranges from **0.93% to 1.54%**.

Fluid inclusion stratigraphy (FIS)



Fluid inclusion stratigraphy testing results in Barnicarndy 1.



Petroleum inclusions found on photomicroscopy in Barnicarndy 1.

Mineral compositions

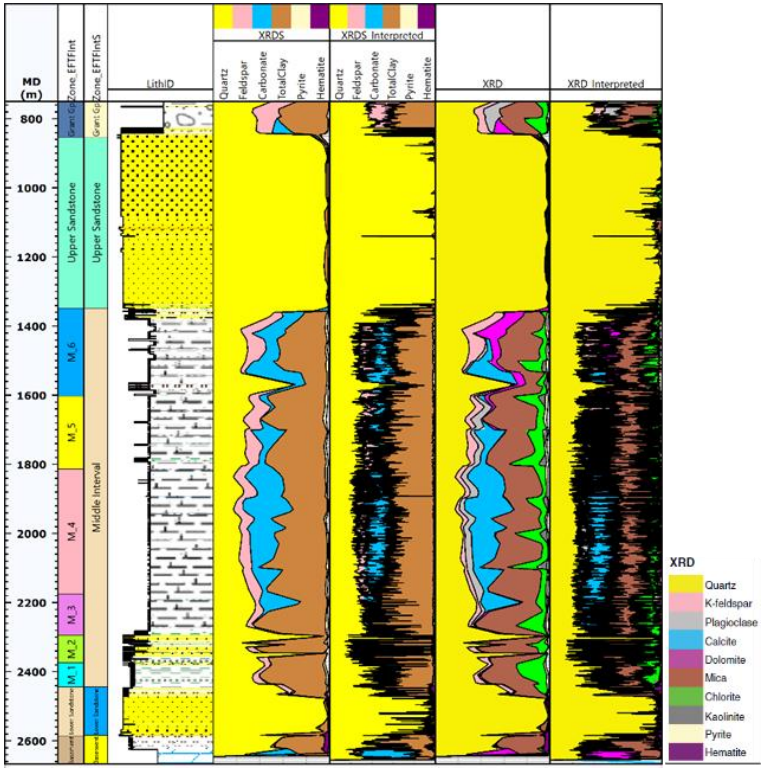
Laboratory tests:

X-ray diffraction (XRD) tests on 99 samples (CoreLab and Bureau Veritas).

Outputs:

- **Ten mineral types:**
  - Quartz, K-feldspar, plagioclase, calcite, dolomite, mica, chlorite, kaolinite, pyrite and hematite contents (wt%)

- **Simplified mineral groups:**
  - Quartz, feldspar, carbonate, clay, pyrite and hematite contents (wt%)



Mineral composition interpretation results in Barnicarndy 1.

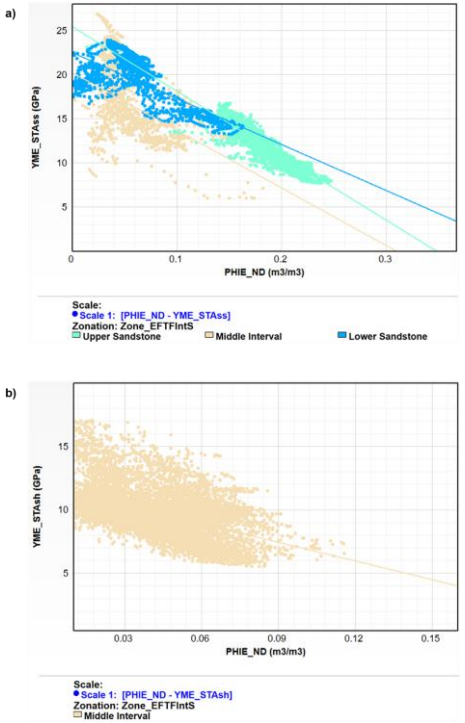
Some findings on Ordovician claystones

Integrated interpretation results in Barnicarndy 1.

Interval	M_6	M_5	M_4	M_3	M_2	M_1
Quartz (wt%)	34.20	29.29	25.62	30.89	32.31	46.37
Carbonate (wt%)	18.77	10.79	19.91	5.72	0.90	0.79
TotalClay (wt%)	35.25	46.17	42.52	50.29	45.78	42.04
YME_STA (GPa)	14.21	6.77	9.35	13.10	18.90	15.93
PR_STA (fraction)	0.142	0.164	0.160	0.152	0.136	0.136

Correlations between TOC and other parameters in Barnicarndy 1.

Parameter	PHIE_ND	Carbonate	YME_STA	PR_STA	logK
TOC	0.4292	0.3632	-0.2430	0.1109	0.3123



Young's modulus versus porosity in Barnicarndy 1.

Conclusions

1) Three major intervals, including Upper Sandstone, Middle Interval and Lower Sandstone, were defined for well log interpretation in the pre-Carboniferous succession in Barnicarndy 1 well. The Middle Interval was further divided into six internal units.
2) High quality reservoirs exist in Upper Sandstone.
3) Mean claystone porosity of 4.2% and permeability of 0.006 mD
4) Average TOC content and S2 of claystone in the Middle Interval are 0.17 wt% and 0.047 mg HC/g Rock. TOC content has a positive correlation with porosity, permeability and carbonate content in the Middle Interval.
5) Average Poisson's ratio and Young's modulus of claystone in the Middle Interval are 0.154 and 9.81 GPa. Young's modulus and Poisson's ratio are well correlated with the contents of key minerals, including quartz, carbonates and TotalClay.
6) Hydrocarbon generation and migration have occurred elsewhere in the Barnicarndy Graben, even though TOC content is low at Barnicarndy 1.

Thank you!

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