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Petrophysical interpretation and reservoir characterisation on Proterozoic shales in NDI Carrara 1, Northern Territory

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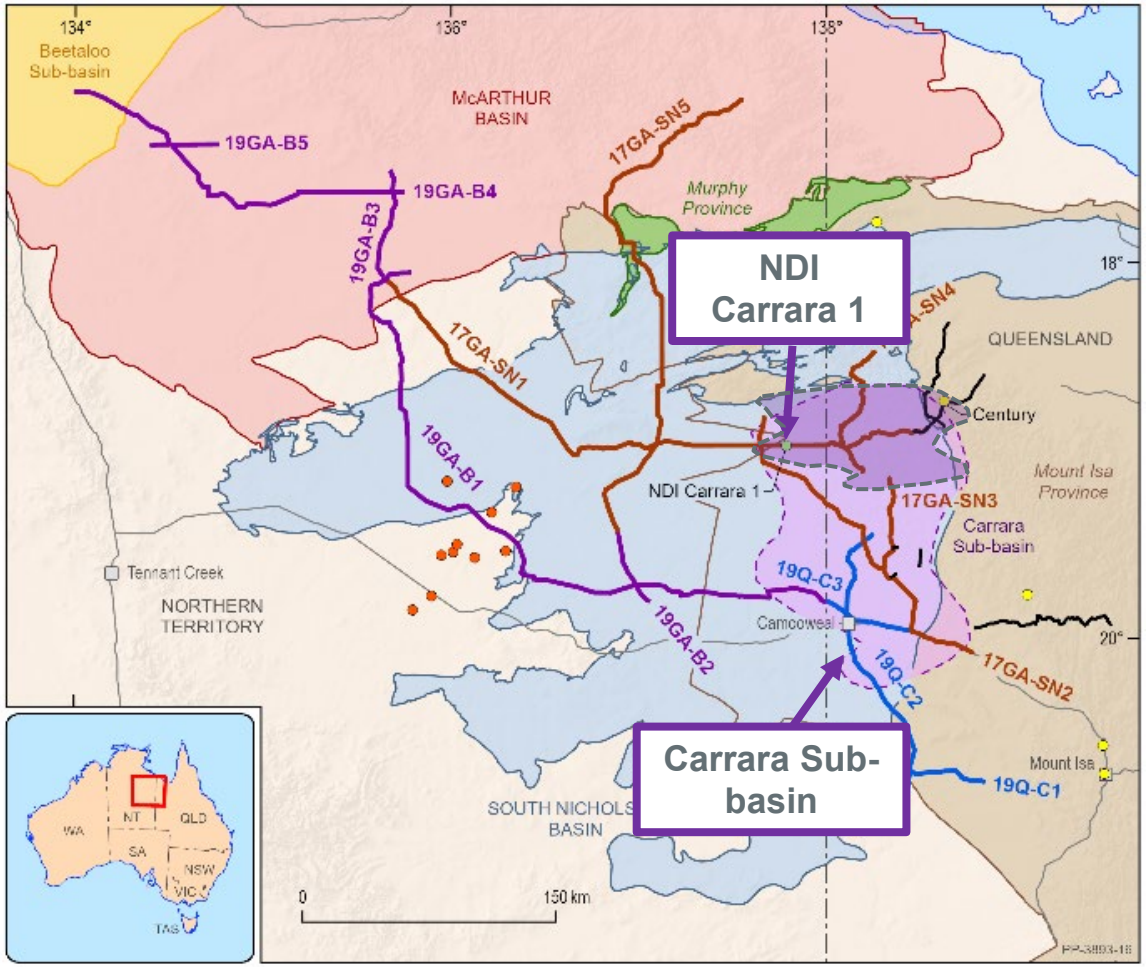
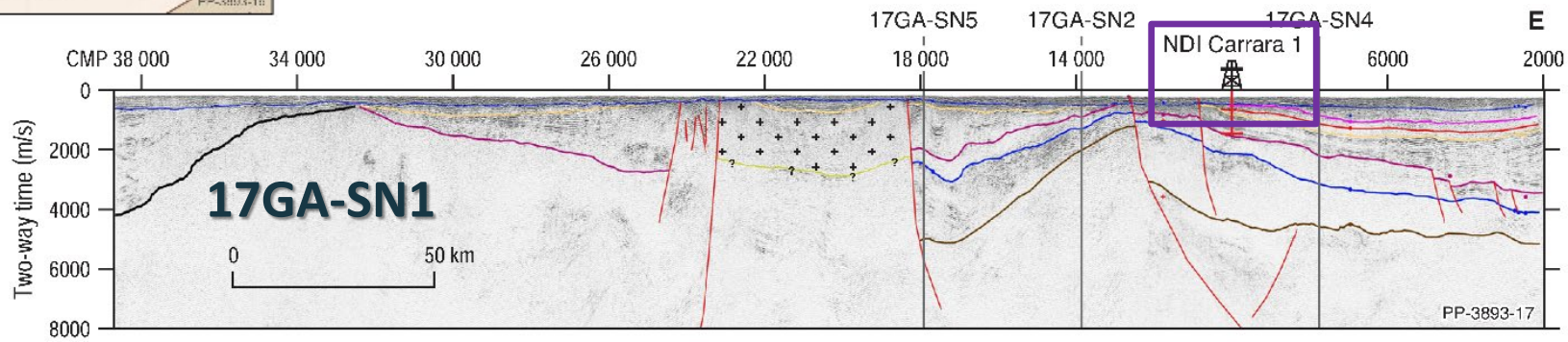
NORTHERN TERRITORY GOVERNMENT

The Carrara Sub-basin and NDI Carrara 1



- Carrara Sub-basin discovered during the EFTF South Nicholson Seismic Survey in 2017
- NDI Carrara 1 located on western flank of Carrara Sub-basin
- Drilling of NDI Carrara 1 completed in Dec 2020
- EOH 1751 m
- 630 m of Cambrian Georgina Basin
- 1121 m of Proterozoic sediments



NDI Carrara 1 drill hole

Macrofossils study (Laurie, 2022)
Middle Cambrian

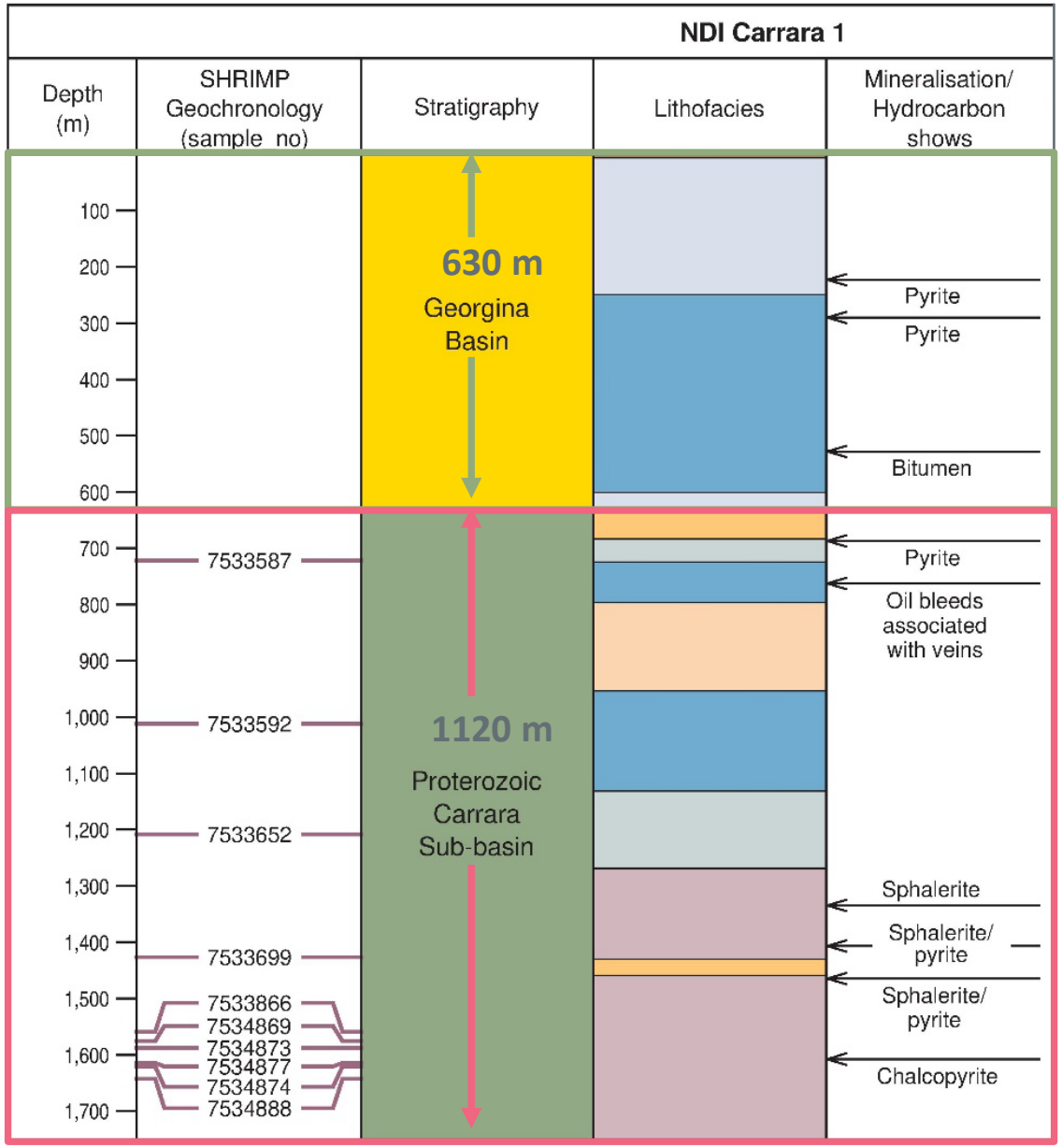
basal unconformity @ 630 m

Equivalent to the Paleo- to Mesoproterozoic middle to upper Lawn Hill Fm.

~ 1588 Ma @1012 m

~ 1601 Ma @1204 m

1611 Ma @1580–1650 m



Work conducted in this study

1) Definition of chemostratigraphic units:

- Packages, and;
- Internal units

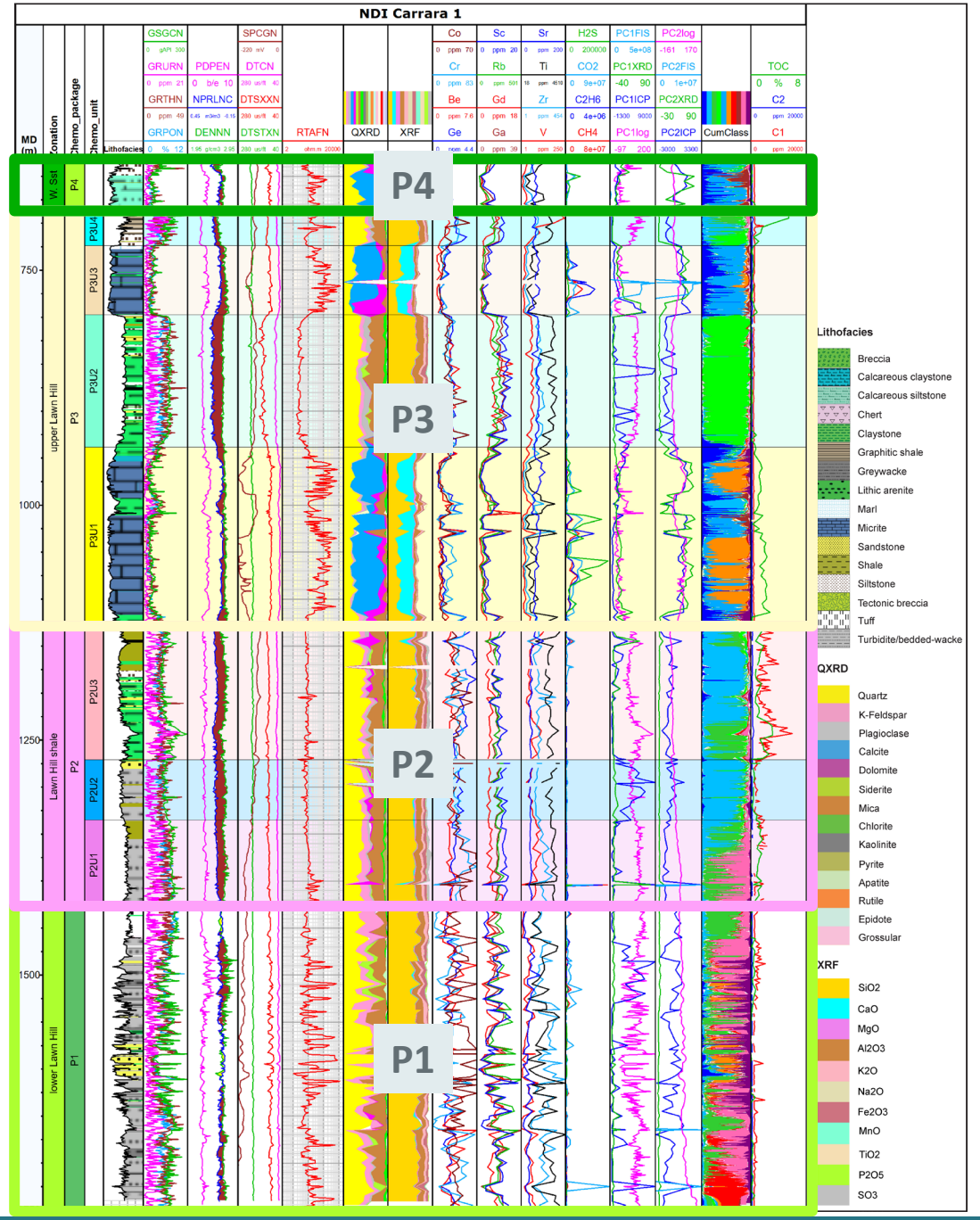
2) Petrophysical interpretation

- Mineral composition
- Total and gas porosity
- Permeability
- Gas saturation
- Adsorbed gas content
- Free gas content

3) Shale reservoir discussion

1) Definition of Chemostratigraphic Packages

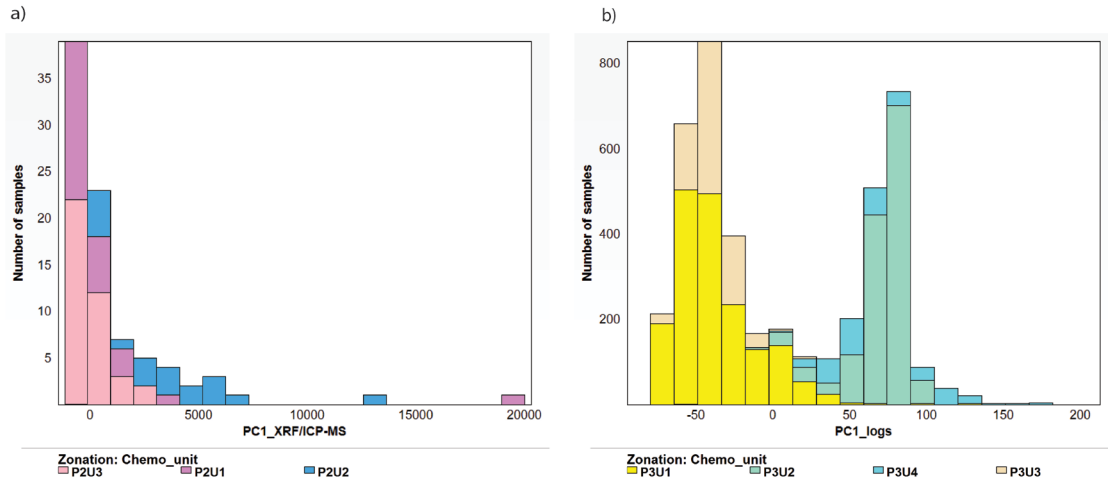
- This study is focussed on the Proterozoic interval
  - This has previously been informally divided into four intervals.
- Four chemostratigraphic intervals were defined in this study and are the equivalent of the previously defined lithostratigraphic units:
  - P1: lower Lawn Hill Formation.
  - P2: Lawn Hill shale
  - P3: upper Lawn Hill Formation
  - P4: Widdallion Sandstone member

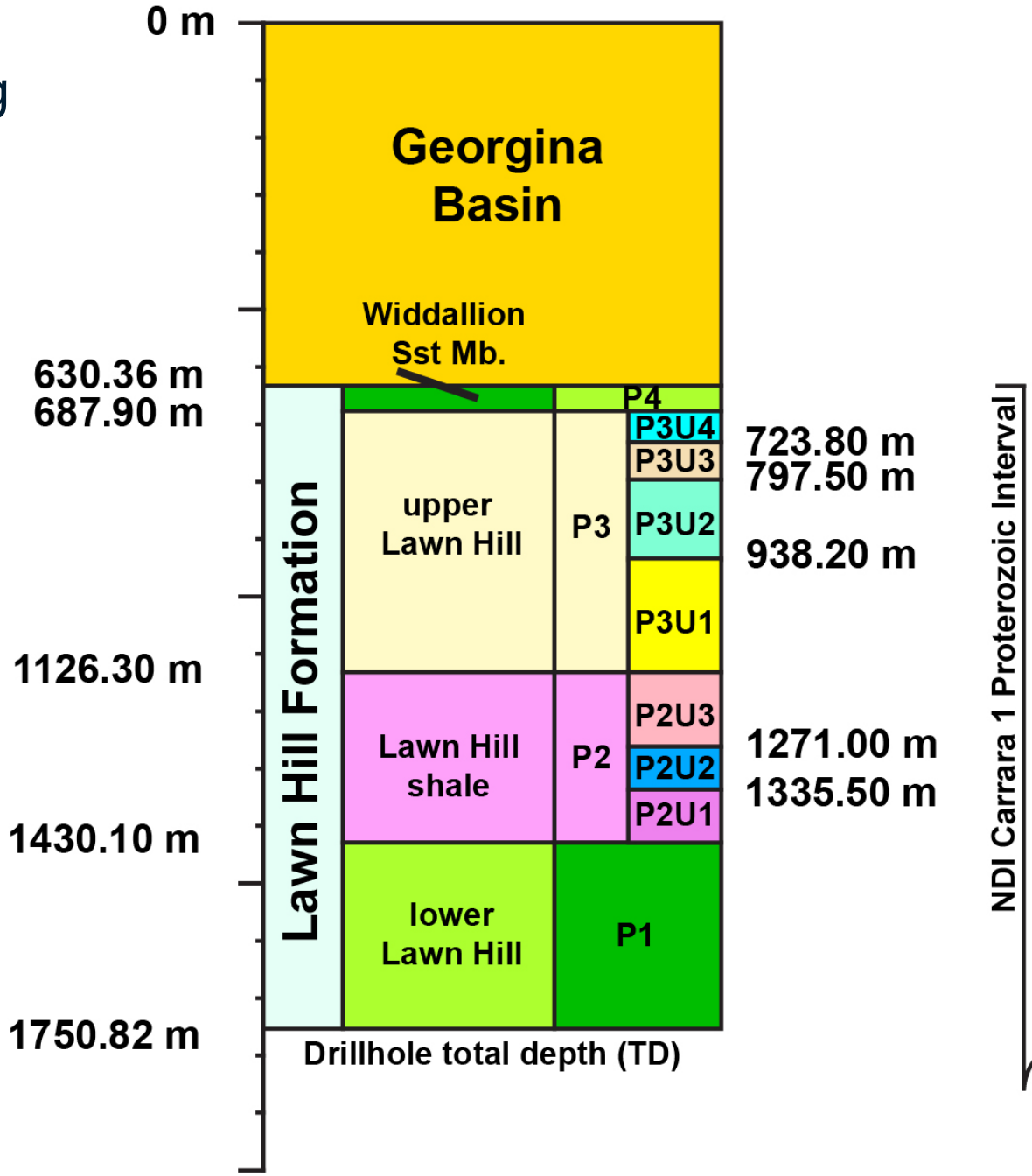


1) Definition of Chemostratigraphic Packag

Defining internal units:

- We are primarily interested in organic-rich shales to analyse as potential shale-gas intervals:
  - P1 and P4 lack significant thicknesses of shales with TOC > 1 wt%
  - P2 and P3 both host shales with TOC >1 wt%
- Therefore, we are focused on P2 and P3.
- These have been further subdivided based on chemostratigraphy

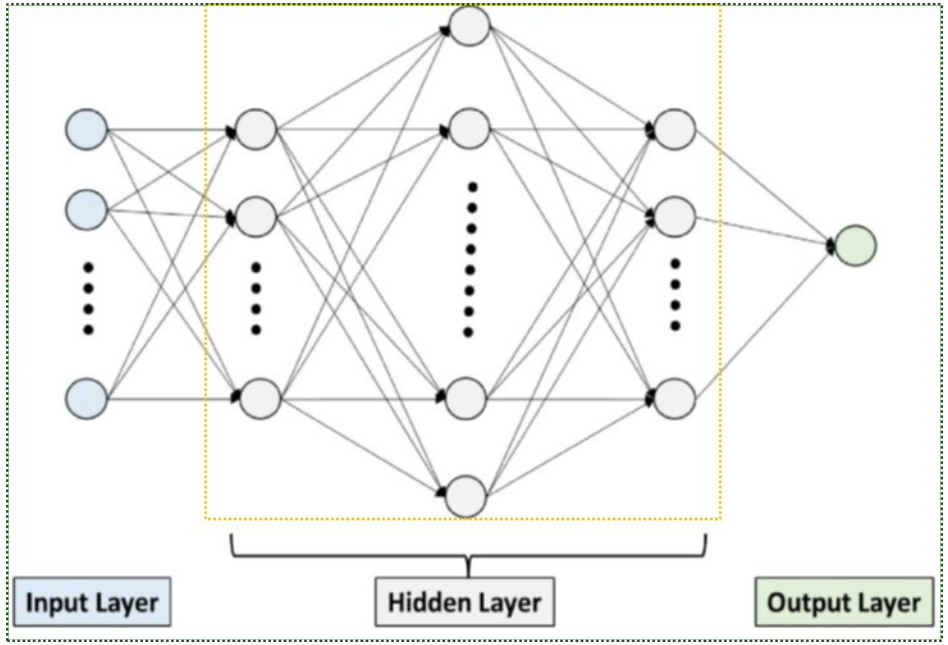




2) Petrophysical Interpretation

Artificial Neural Networks (ANN)

- ANNs were used to interpret petrophysical properties
- This was a two stage process:
  - 1) Training the ANN using training patterns that include both inputs (e.g. well logs) and outputs (e.g. lab measurements).
  - 2) Prediction of outputs (properties) from input data (e.g. well logs) at unsampled locations using the trained ANN.
- Inputs in this case were well logs, including:
  - Spectral gamma ray (uranium, thorium and potassium concentrations).
  - Neutron porosity, bulk density, compressional wave slowness
  - Logarithmic deep resistivity
- Testing patterns = 20% of all patterns



2) Petrophysical Interpretation

Mineral Composition:

- QXRD results highlight 14 mineral groups:
  - Dominant minerals (red)
  - Minor-content minerals (green)
- These can be summarised as major (grouped) minerals and inorganic carbon content.

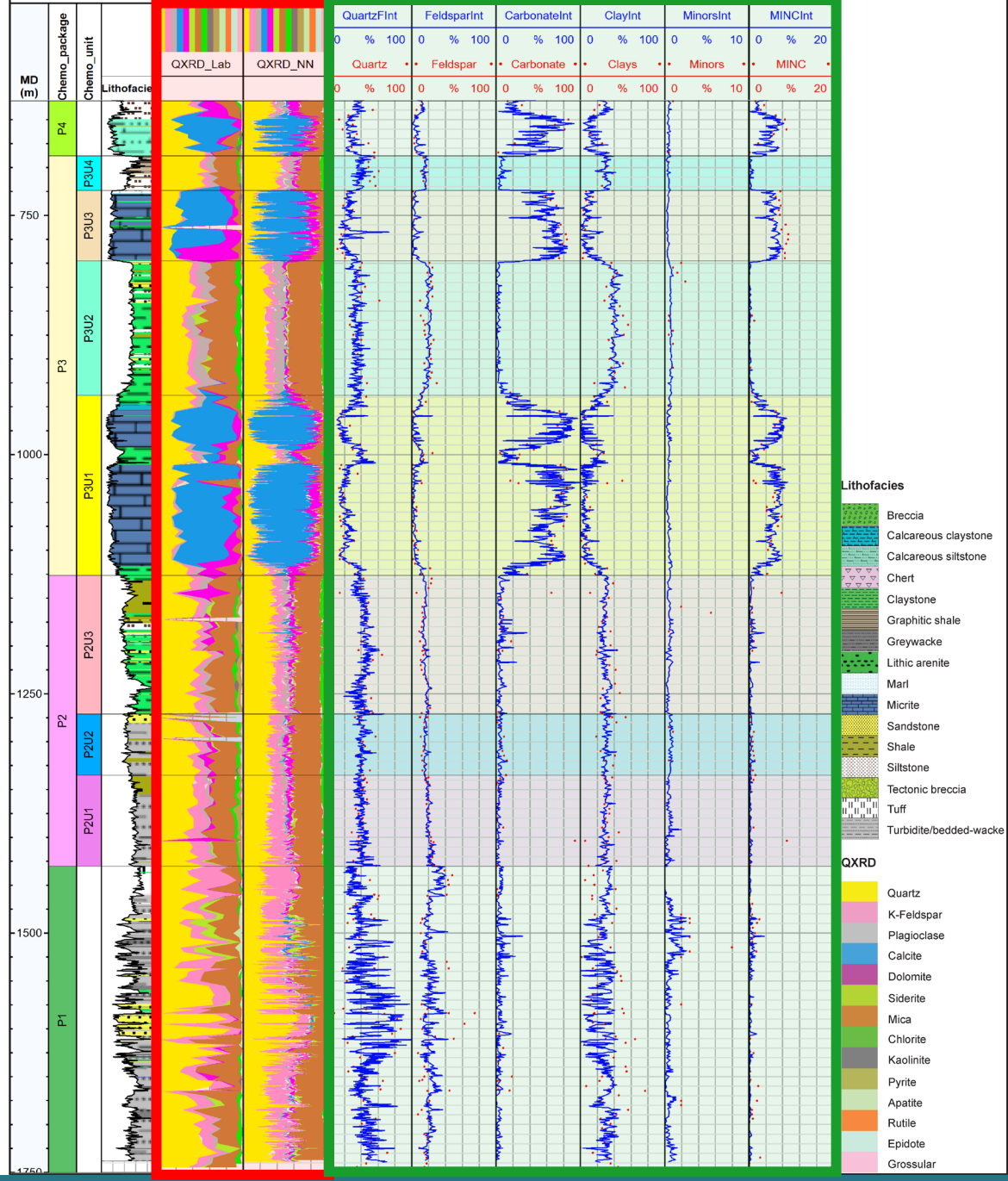
Mineral	Maximum (%)	Average (%)
Quartz	87	38.33
K-feldspar	75	11.74
Plagioclase	24	3.92
Calcite	83	12.53
Dolomite	94	5.38
Siderite	31	1.41
Mica	77	22.69
Chlorite	9	2.24
Kaolinite	7	0.28
Pyrite	11	1.18
Apatite	10	0.18
Rutile	2	0.04
Epidote	5	0.04
Grossular	2	0.02

Mineral	Maximum (%)	Average (%)
Quartz	87	38.33
Feldspar	94	15.66
Carbonate	94	17.91
Clay	77	25.21
Minors	10	0.27
MINC	9.4	1.83

2) Petrophysical Interpretation

Mineral Composition:

- Mineral assemblage was interpreted via ANN:
  - Interpreted mineral assemblage (red) correspond to the variations in lithological sequence and well logs.
  - Interpreted mineral compositions (green) correlated highly with the QXRD measurements (red dots).



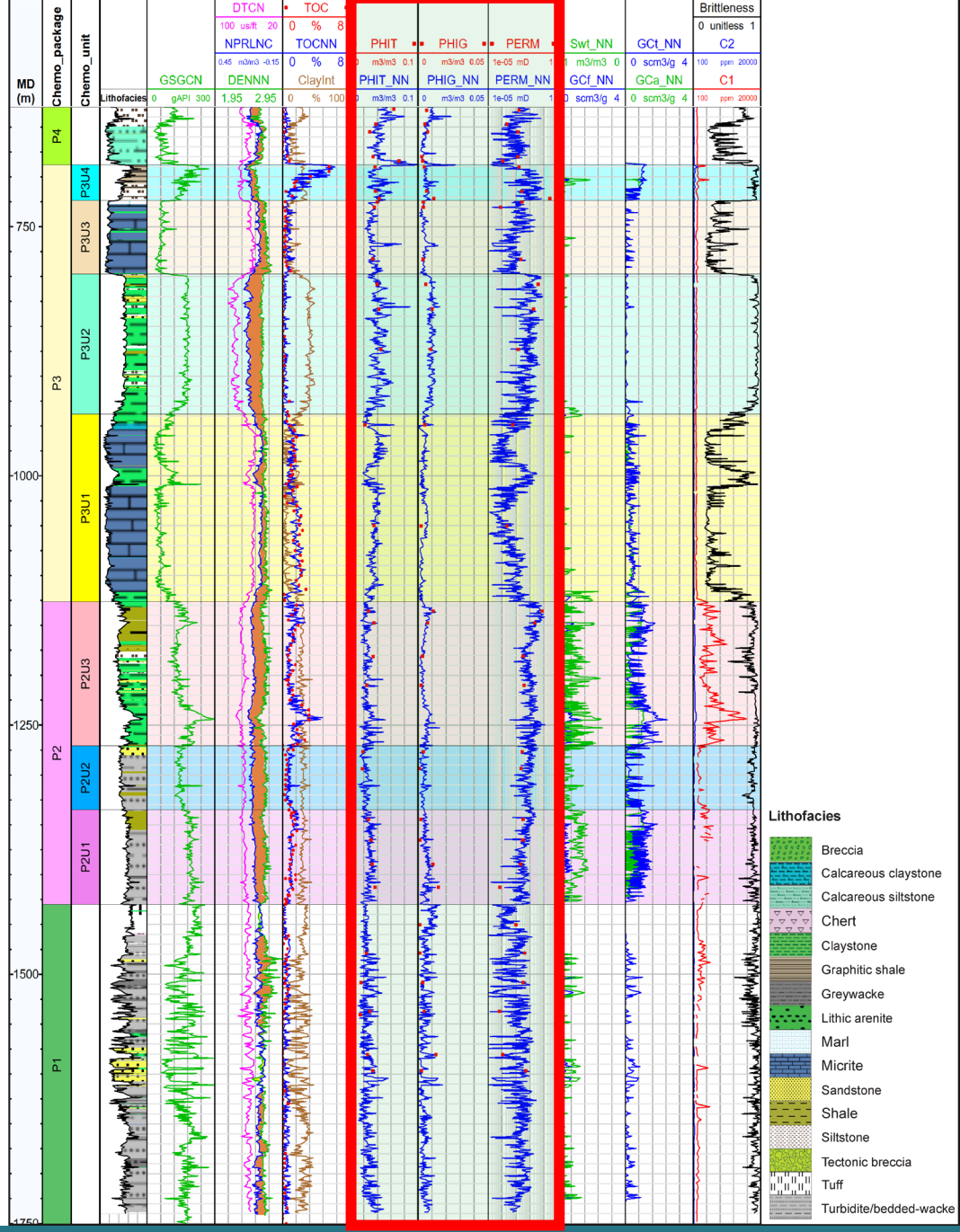
2) Petrophysical Interpretation

Porosity and Permeability:

- Core plugs were tested by CSIRO Energy for porosity and permeability:

Statistics	Total porosity (%)	Gas porosity (%)	Permeability (μD)
Minimum	1.45	0.12	0.1
Maximum	7.22	1.44	263.0
Average	**3.35**	**0.54**	**1.9**
Median	3.34	0.42	2.3

- ANNs were used to build a more detailed understanding of poroperm in NDI Carrara 1:
  - Outputs:
    - Total Porosity
    - Gas Porosity
    - Logarithmic Permeability

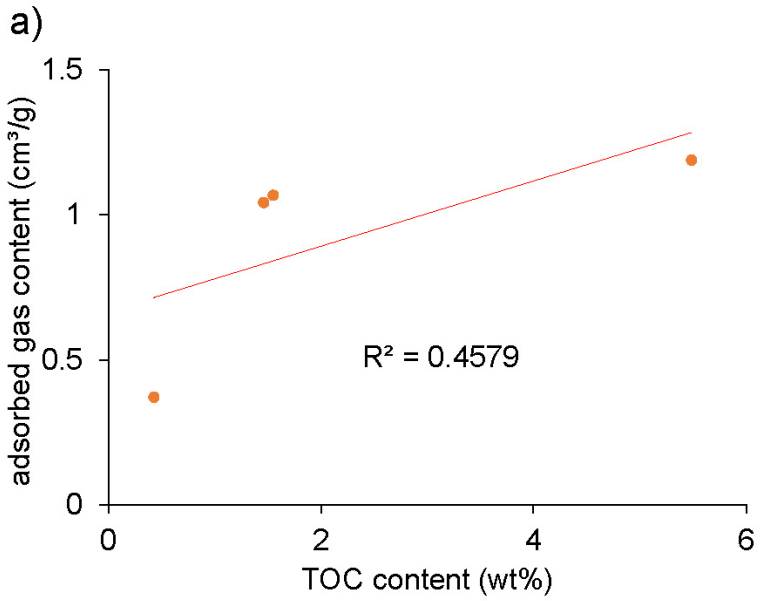


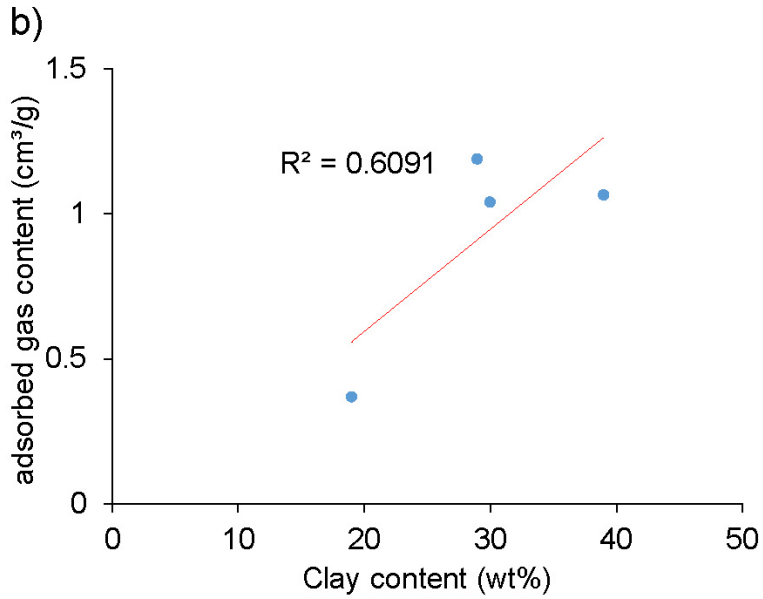
2) Petrophysical Interpretation

Adsorbed Gas Content:

- Four shale samples were sent to CSIRO Energy for isotherm adsorption and desorption testing.
  - adsorbed gas content of **up to 1.19 g/cm^3**
- Positively correlated with both:
  - TOC content (a)
  - Clay content (b)
- From these correlations, the below relationship can be constructed:

$$\boldsymbol{Adsorbed\ gas\ content\ (GC_a)} = \mathbf{0.0891} \times (\boldsymbol{TOC\ content, wt\%}) + \mathbf{0.025} \times (\boldsymbol{Clay\ content, wt\%}$$

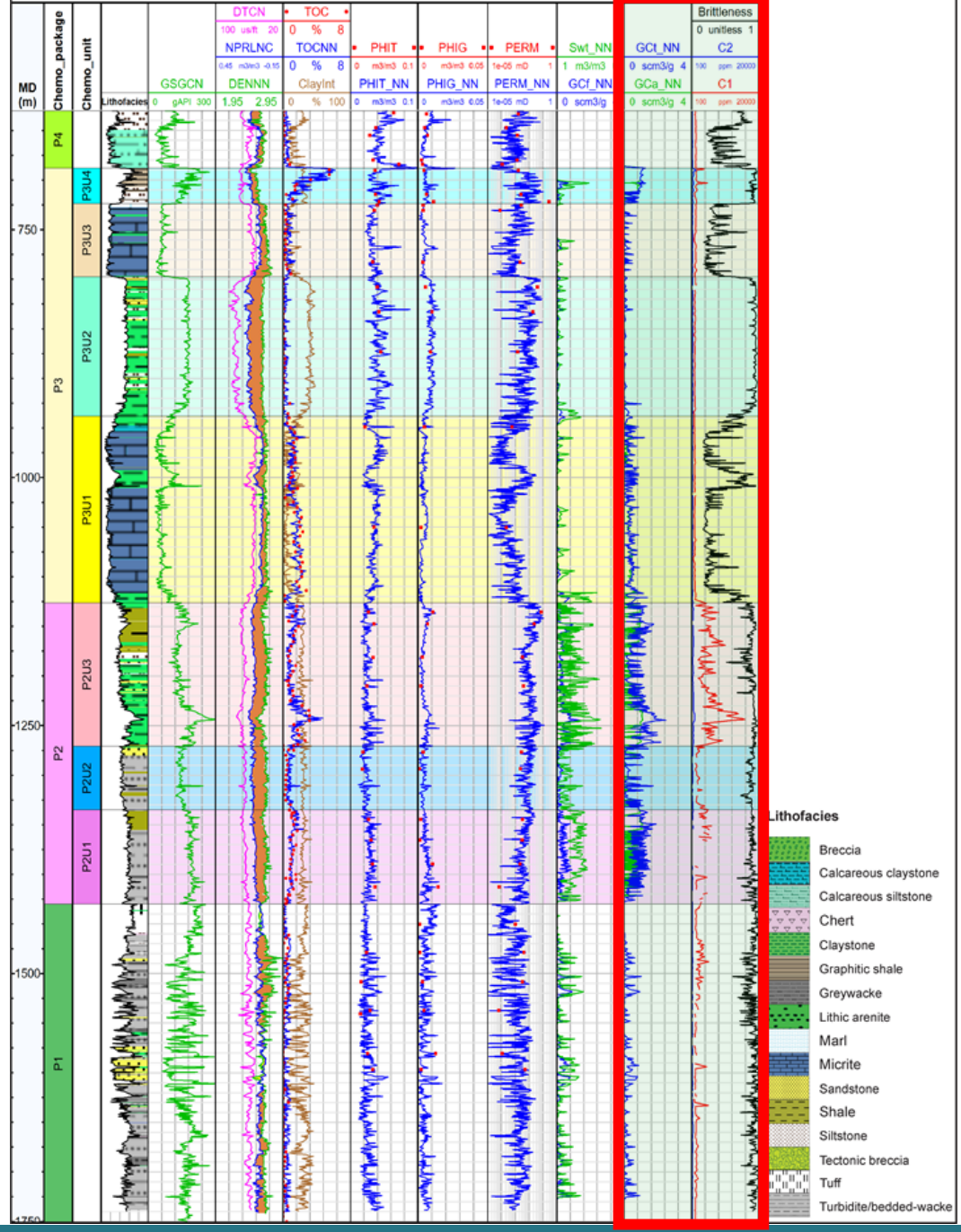




2) Petrophysical Interpretation

Water saturation and free gas content:

- Conventional interpretation methods were used to estimate:
  - Formation water resistivity
  - Total water saturation
  - Total gas saturation
  - Free gas content
- These values were extrapolated throughout the section via trained ANNs.
- Total gas content was calculated from absorbed and free gas contents.

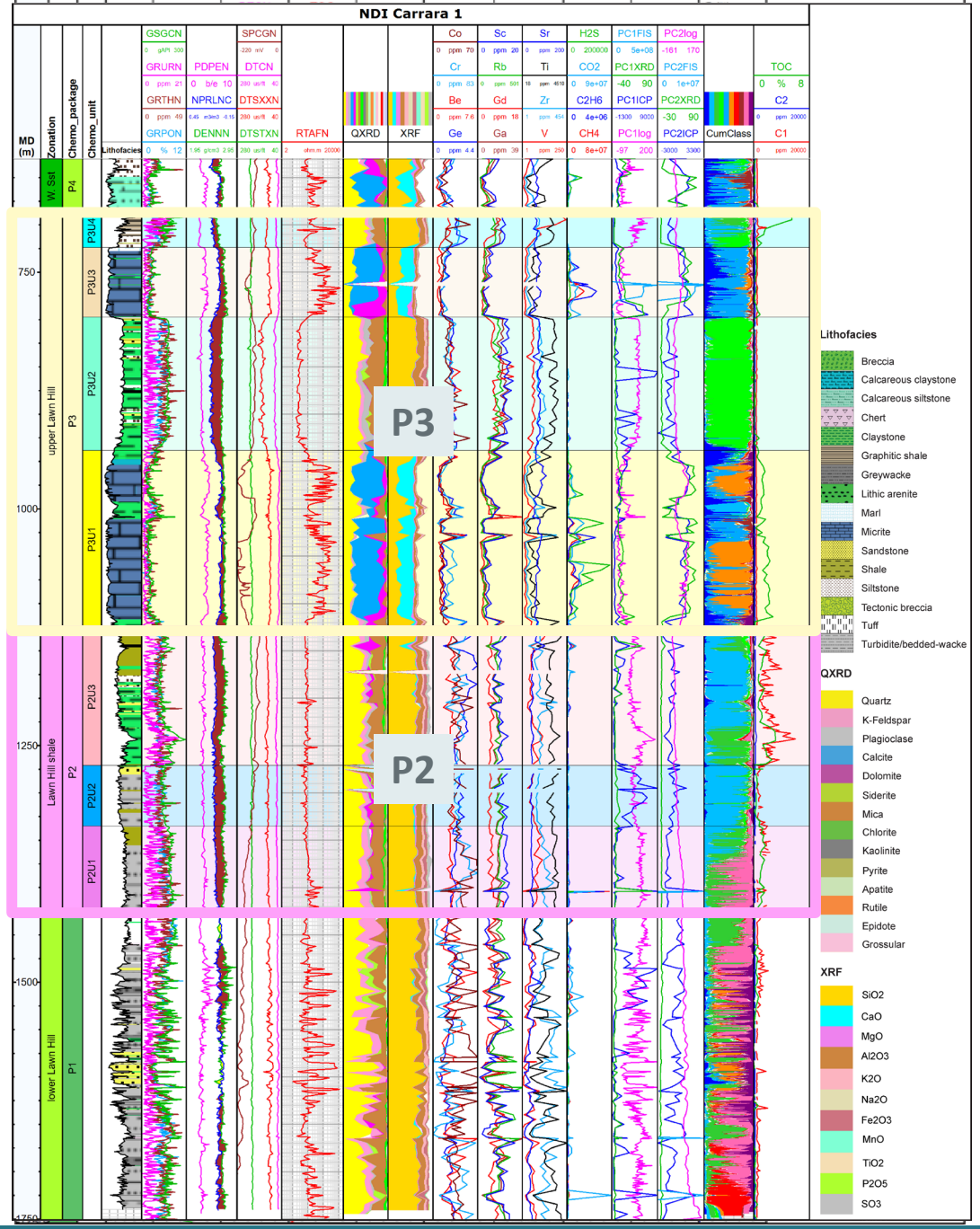


3) Shale Reservoir Characterisation

There are clear indications of shales that may be suitable as shale gas reservoirs in NDI Carrara 1:

- Favourable shale mineralogy,
- Shale intervals with high TOC contents + associated gas peaks,
- Encouraging porosity and permeability data,
- Demonstrated ability for shales to adsorb methane,
- Elevated gas saturations,
- Potentially brittle (after Bailey et al., 2022).

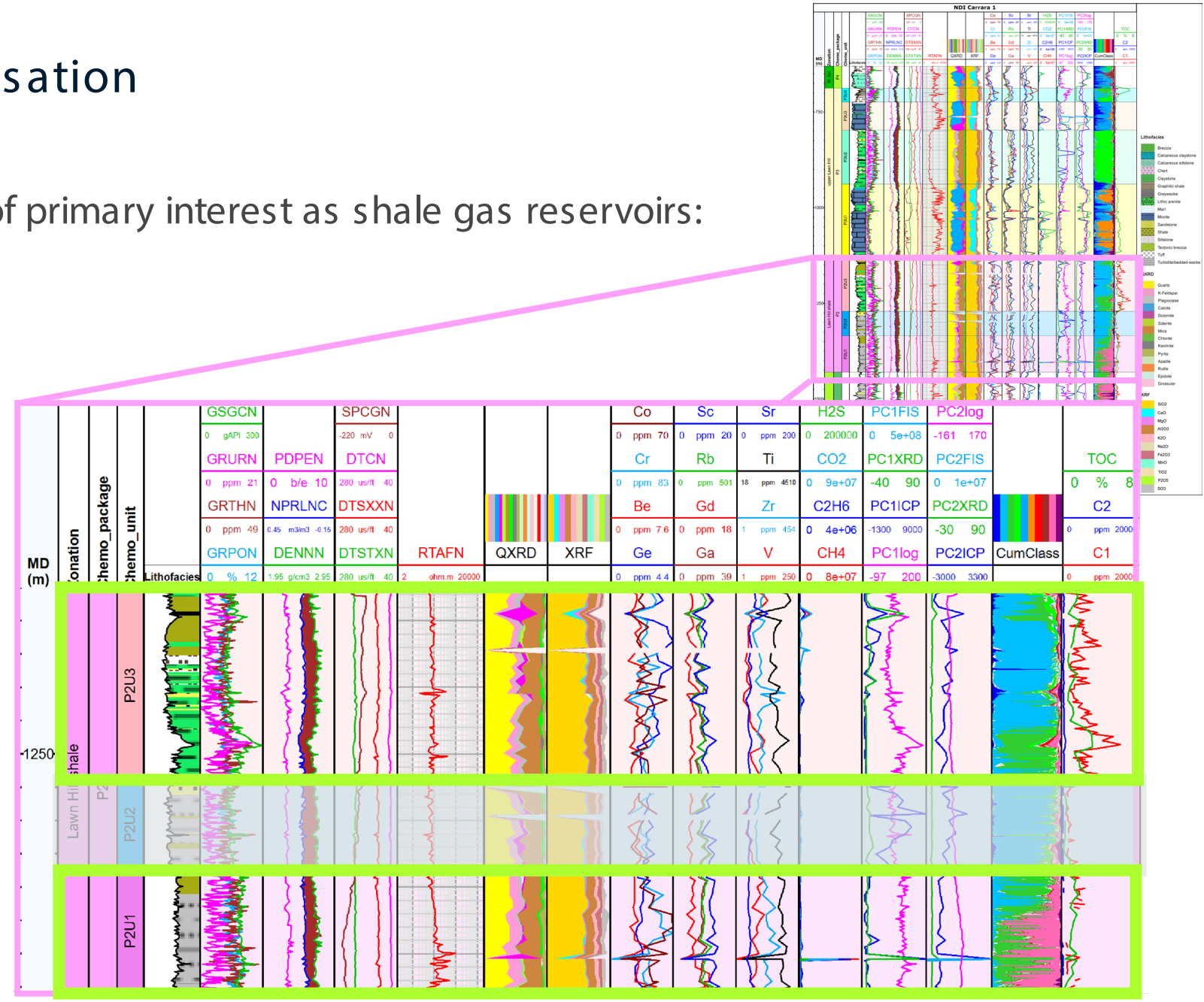
- These shales are identified in P2 and P3



3) Shale Reservoir Characterisation

P2 shales:

- In Package 2, Unit 1 and Unit 3 are of primary interest as shale gas reservoirs:
  - Porosity > 2%,
  - Elevated gas saturations and gas contents,
  - Net shale thickness of 53.5 m (U1) and 83.3 m (U2),
  - High methane peaks:
    - U1 (max. = 5,967 ppm)
    - U3 (max. = 15,807 ppm)
- Unit 2 has very low net shale thickness (13.5 m)

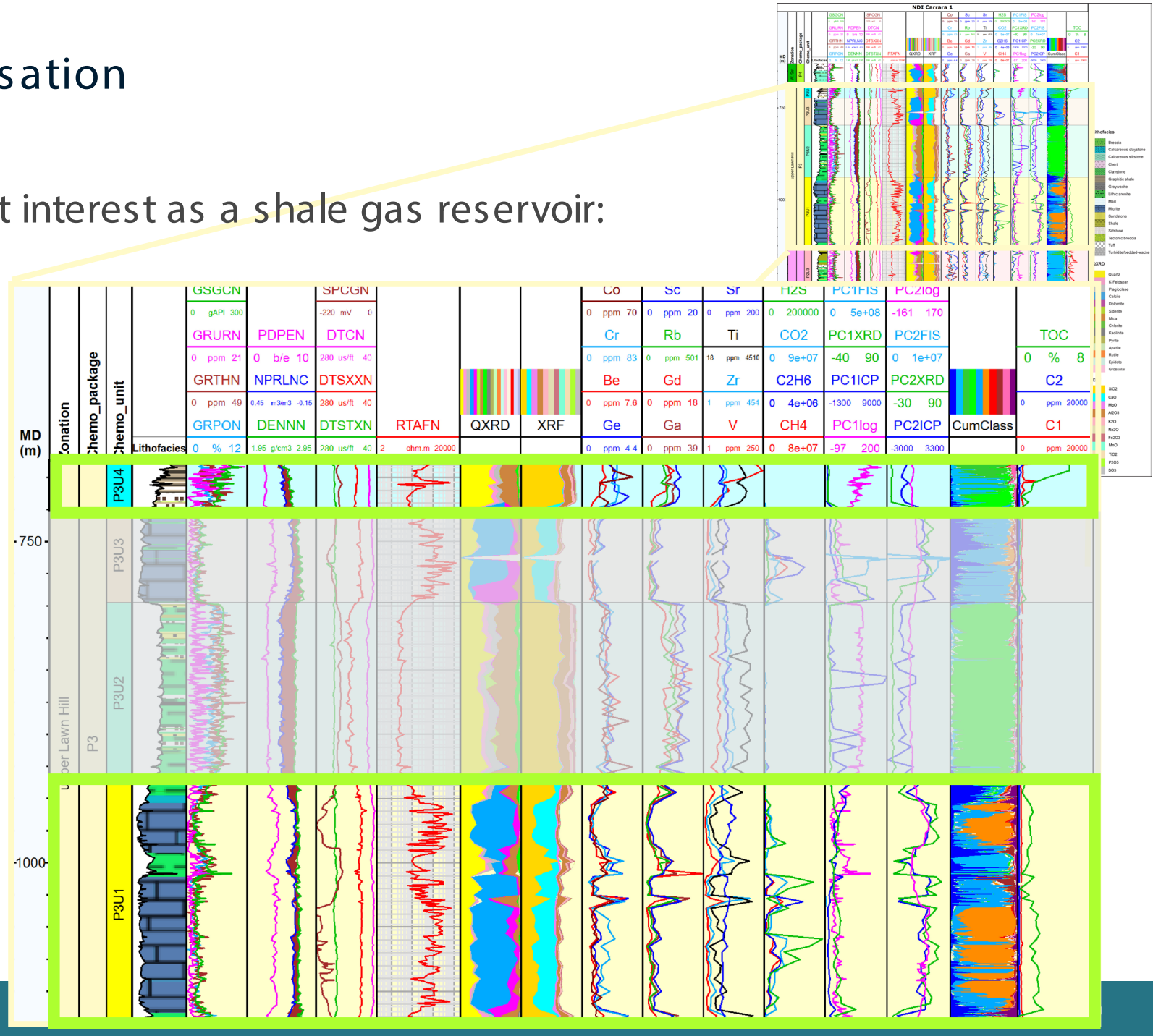


3) Shale Reservoir Characterisation

P3 shales:

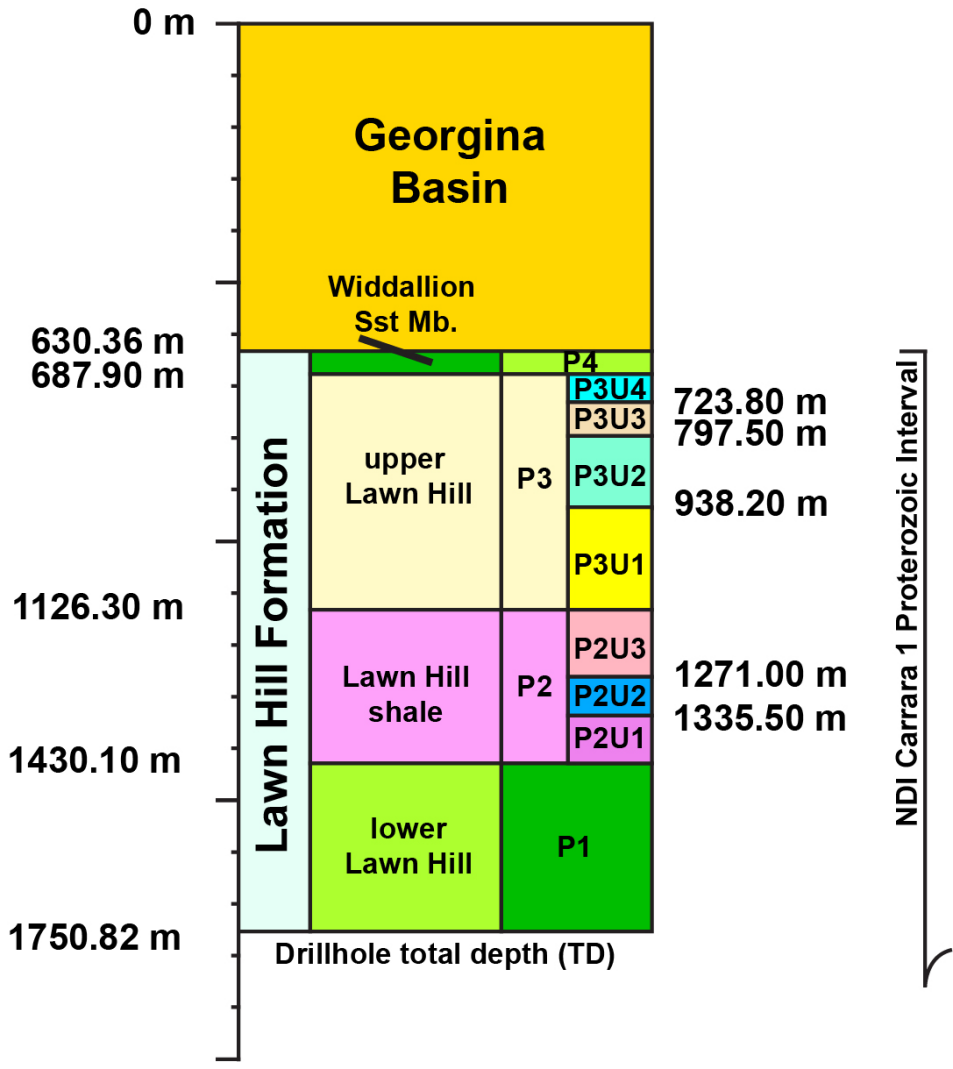
- In Package 3, Unit 4 is of the most interest as a shale gas reservoir:
  - Porosity > 2%,
  - Elevated gas saturation and gas content,
  - Net shale thickness of 30.6 m High methane peak (3,838 ppm)

- Unit 1 does have high TOC and adsorbed gas contents, however:
  - Consists of micrite, marl and calcareous shales,
  - Very low gas saturation and free gas content.
- Net shale thicknesses of Unit 2 and Unit 3 are negligible.



Conclusions

1. **Four chemostratigraphic packages are defined within the Proterozoic interval of NDI Carrara 1 (Package 1 – 4).**
   - Package 2 and Package 3 host significant organic-rich shales and are of interest as potential shale gas reservoirs.
   - These are further subdivided into sub-units for analysis.
2. **Artificial Neural Networks (ANNs) were used to create continuous curves of petrophysical rock properties.**
   - ANNs were trained on laboratory measurements and values derived from conventional wireline log interpretations.
3. **Package 2 and Package 3 are identified as hosting potential shale gas reservoirs:**
   - P2 Unit 1 and Unit 3 are of primary interest as they have the most favourable petrophysical properties (i.e., elevated gas levels, net shale thicknesses, etc).
   - P3 Unit 4 also has broadly favourable petrophysical properties.
   - P2 Unit 2 and P3 Unit 1 may have some potential, indicated by elevated TOC and adsorbed gas contents.

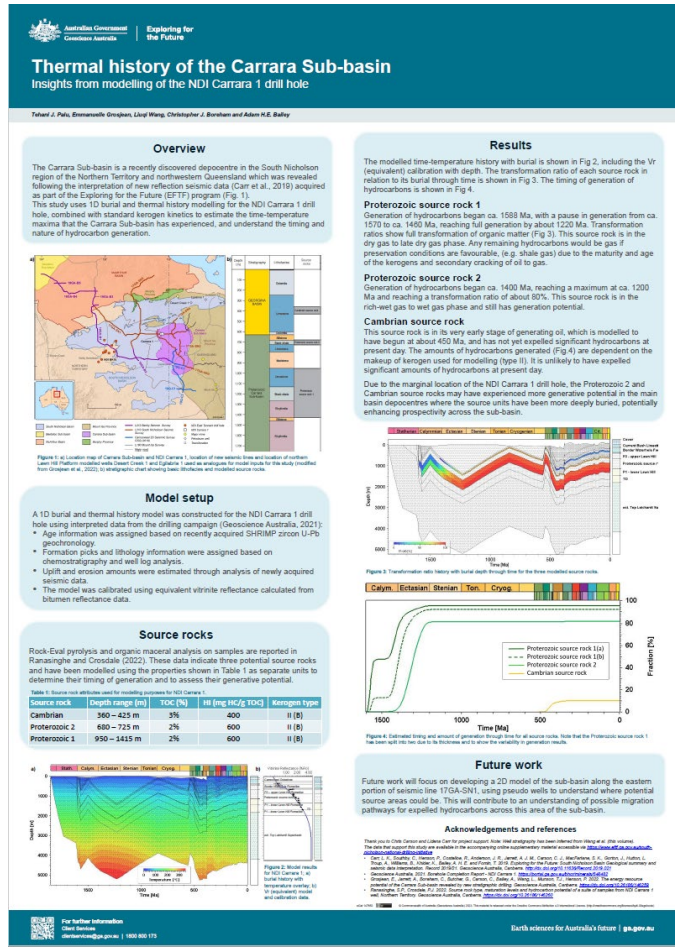


Thanks and questions

…And another thing!

‘Thermal History of the Carrara Sub-Basin’

- Exhibition hall visual presentation
- Meet the author session Tomorrow 1 – 2 pm
- New thermal modelling data



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