14–17 JUNE 2021 PERTH, WA
APPEA
CONFERENCE AND EXHIBITION

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Implications of thin laminations on pore structure of marine shale reservoir: Goldwyer Formation Case study from Western Australia

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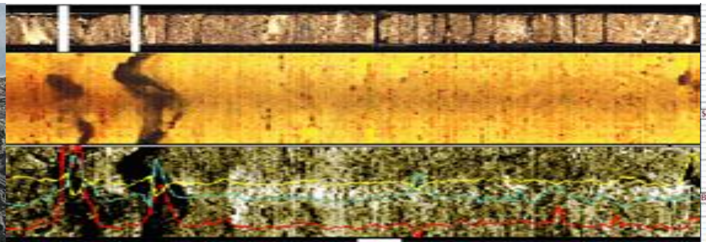
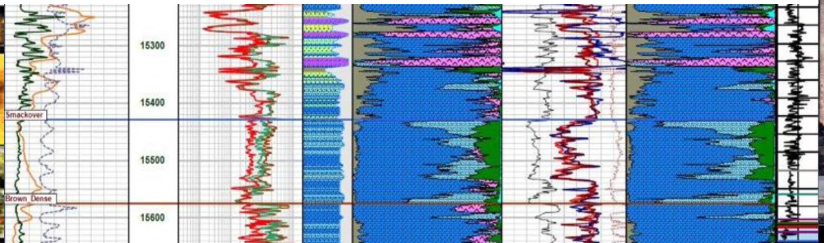
17/06/2021


AGENDA

Contents

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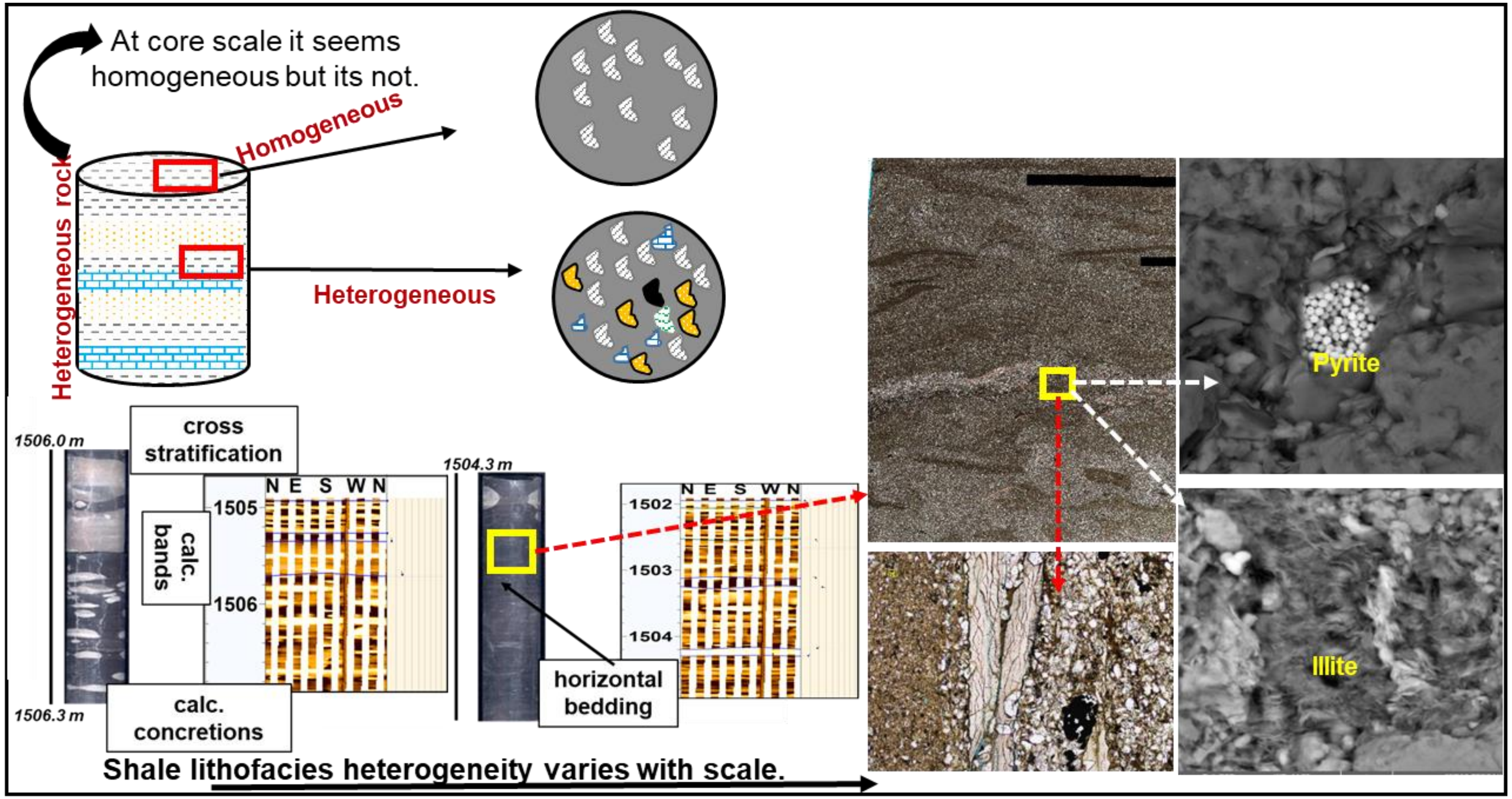
Motivation: Why Rock Typing?

Rock/Matter	GR	Resistivity	Bulk Den	PEF	NPHI	DT slowness	U
Shale (Gas)	V high	high	low	low	low	high	high
Kerogen	500-4000 gAPI	-	0.95-1.05 g/cc	-	50-65 pu	165 μs/ft	0.18-0.24



Shale seems homogeneous at log / core scale.

However, its highly heterogeneous at finer scale.

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Research Questions?

- Not every shale is alike: Shale is thick and heterogeneous?
- The identification of suitable producible zones is very challenging?
- Why pore structure understanding is crucial?
- Shale is fine grained, multiscale approach for heterogeneity is missing?
- Total gas content of shale is highly affected by different geological and petrophysical parameters, such as thin laminations?

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Objectives

i. To classify the shale into different rock types for understanding the heterogeneity.

ii. To recognise the influence of thin laminations on petrophysical properties such as pore structure.

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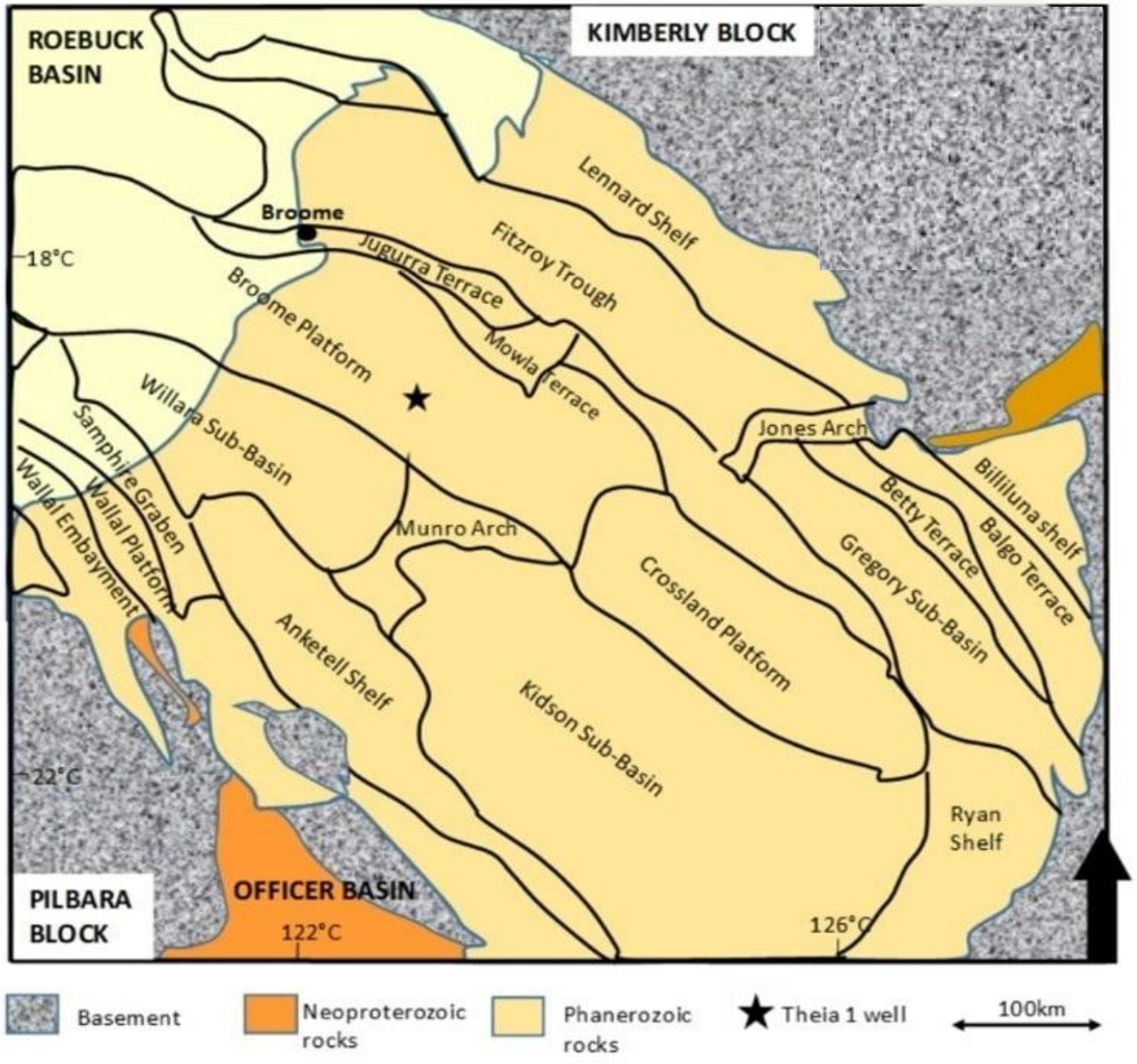
Study Area

- The onshore Canning Basin is situated in the North-Western part of Australia with more than 595,000 km^2
- This research is focused on Ordovician Goldwyer Formation drilled in Theia-1 well, Broome Platform Canning Basin (as shown by black star)



(Johnson, 2019)

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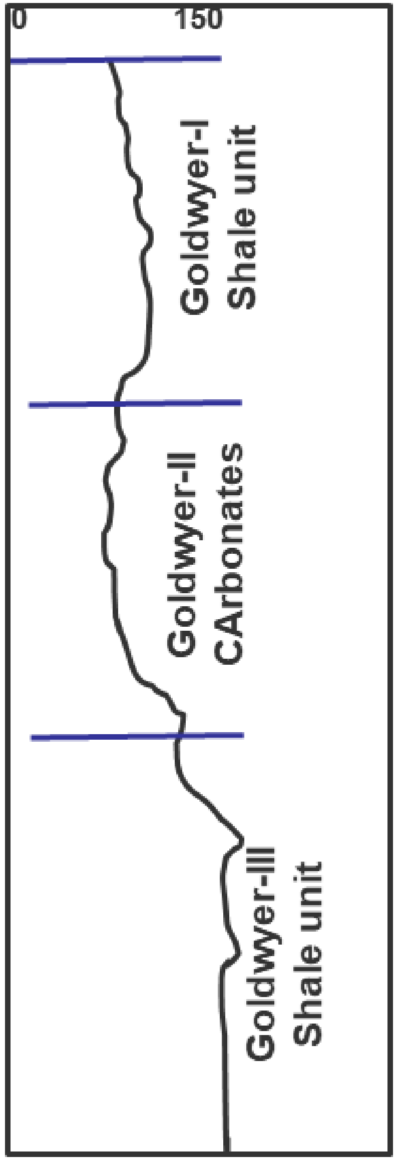
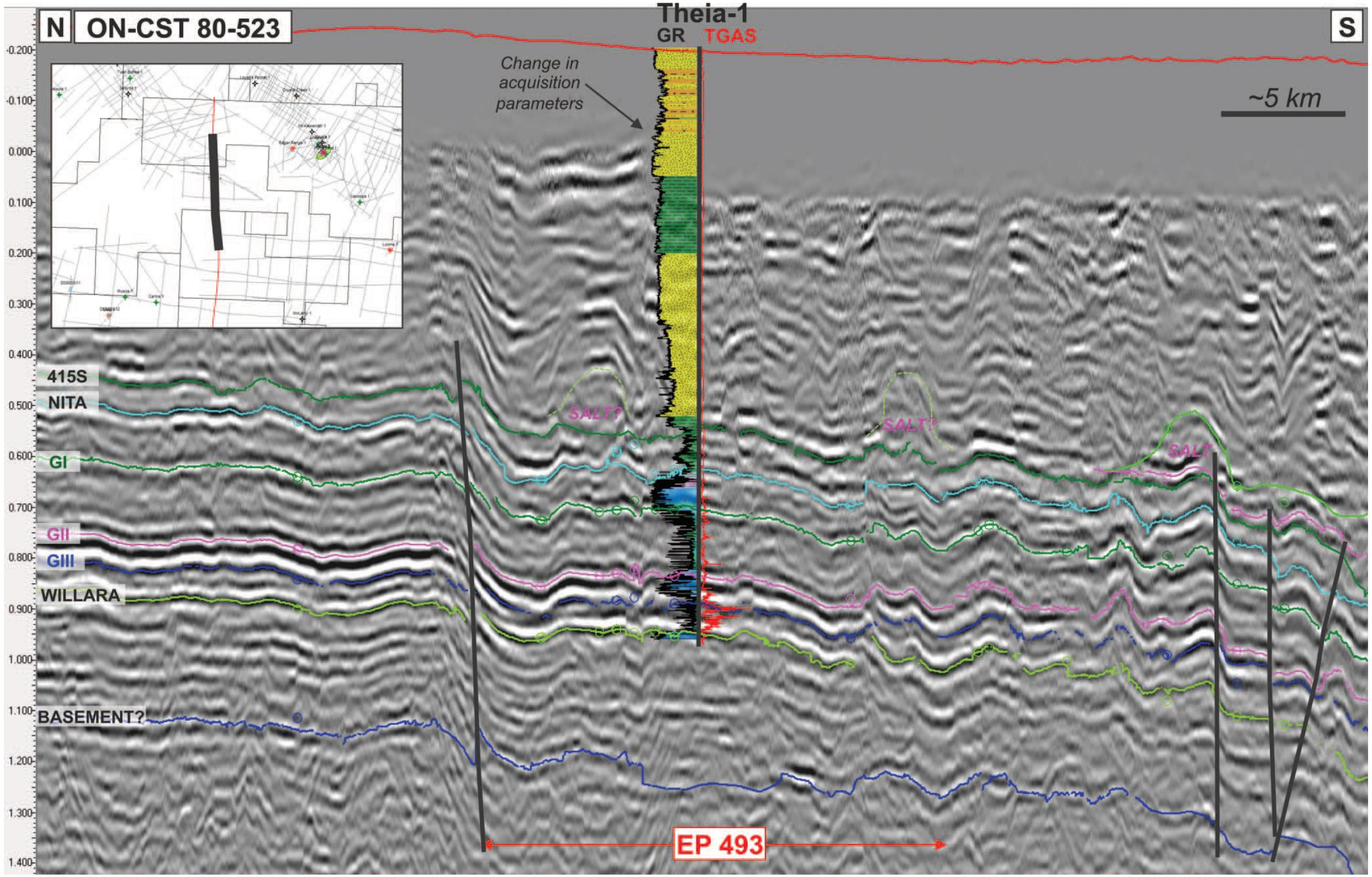
Study Area





(Van Hattum et al., 2019)

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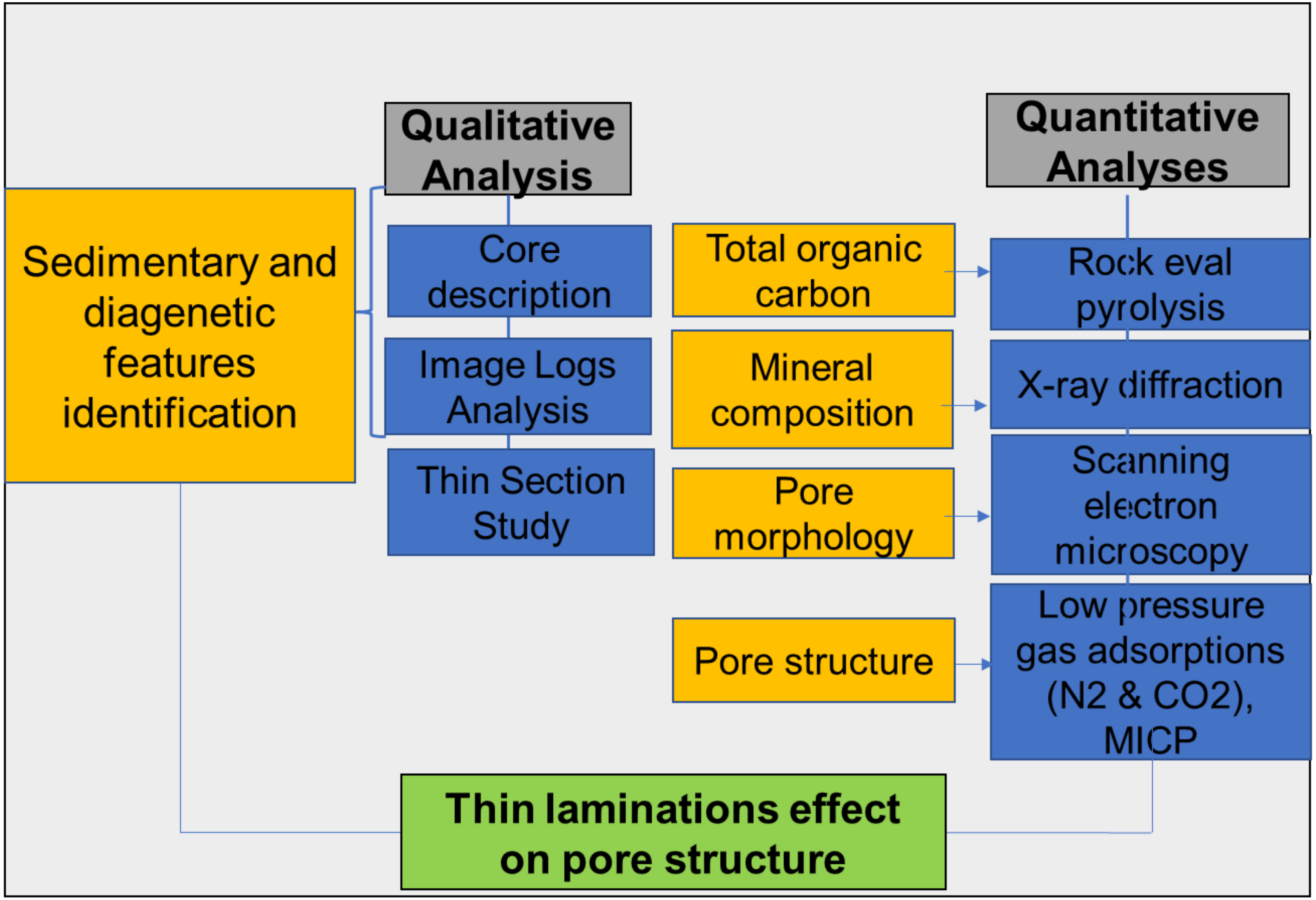
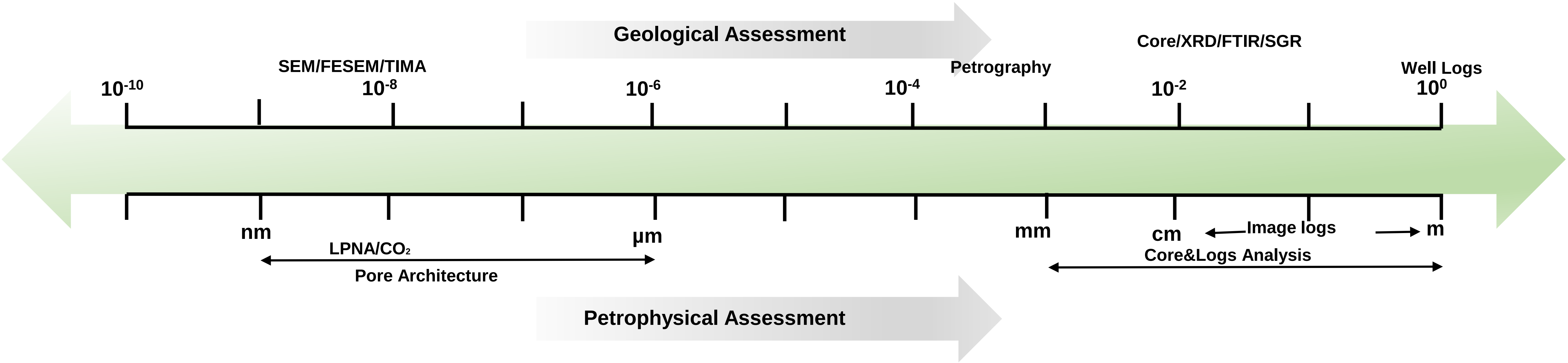
Proposed Workflow



Overview



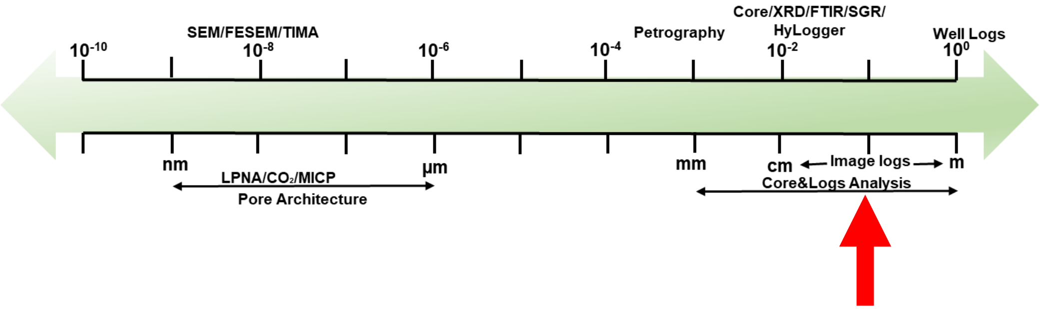
Multiscale approach is applied to identify different rock types and to characterize them with respect to geological and petrophysical properties.

Results and Discussion – Part 1

Sedimentary facies Identification of Goldwyer (III) Formation

Based on core description and image logs analysis, four sedimentary facies have been identified in Goldwyer-III shale, such as:

- Thinly laminated shale (TLSh)
- Concrectionary-banded shale (CSh)
- Massive black shale (MBSh)
- Heterolithic shale (HSh)



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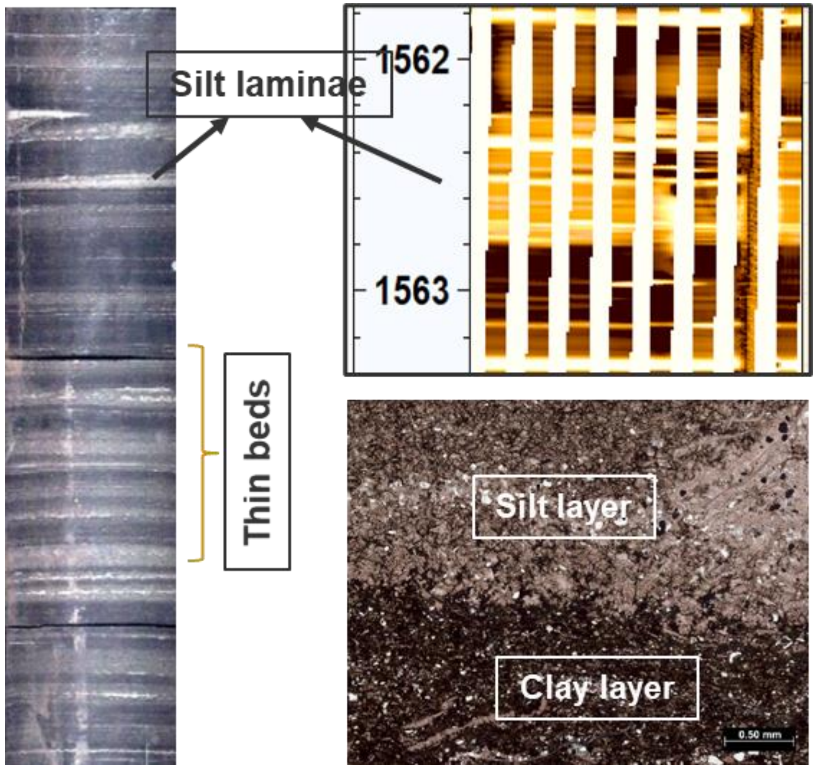
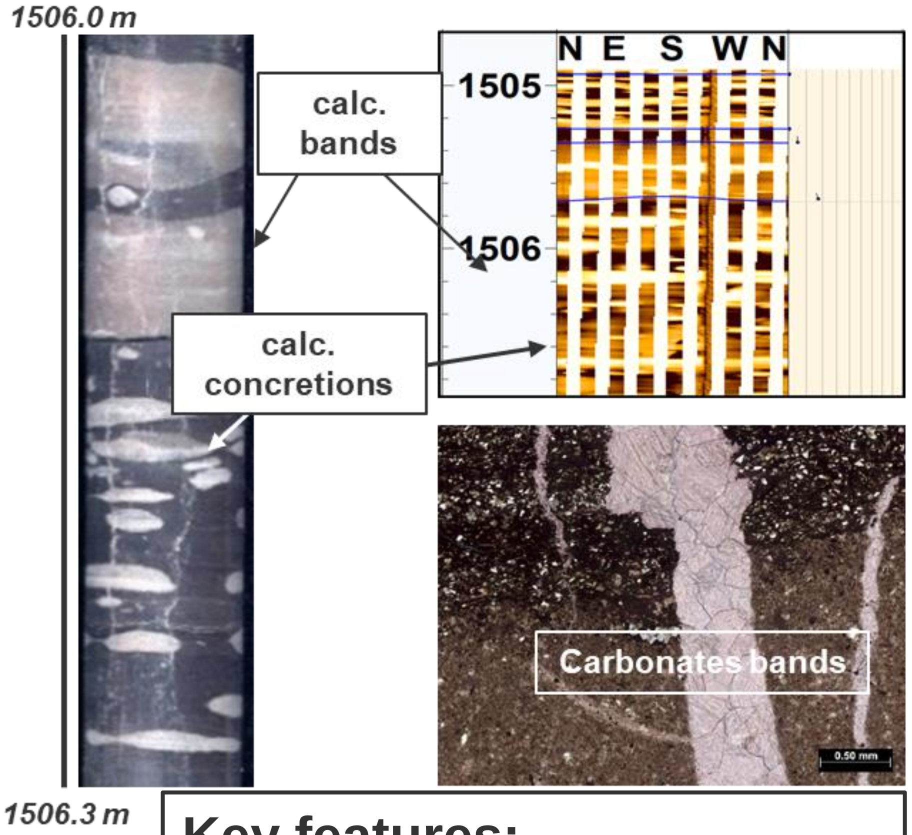
Results and Discussion – Part 1: Sedimentary facies

Thinly Laminated Shale (TLSh)



Key features:
- Silt laminations
- Thinly bedded
- Cross laminations

Concretionary-banded Shale (CSh)



Key features:
- Carbonates bands
- Carbonates concretions
- Bioturbated

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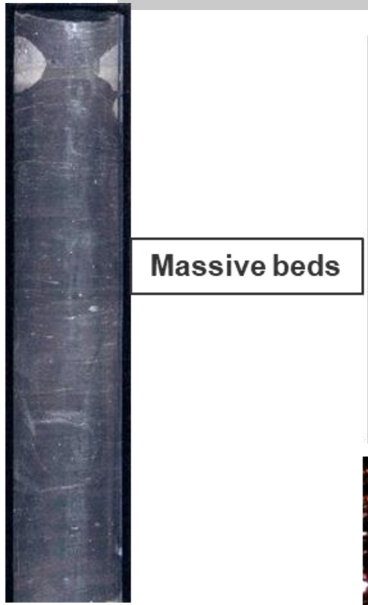
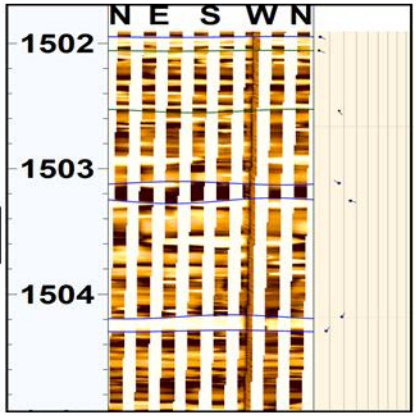
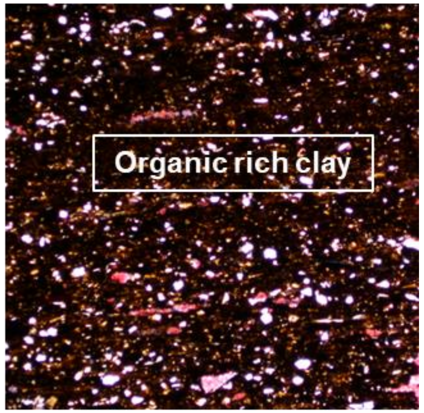
Results and Discussion – Part 1: Sedimentary facies

Massive Black Shale (MBSh)

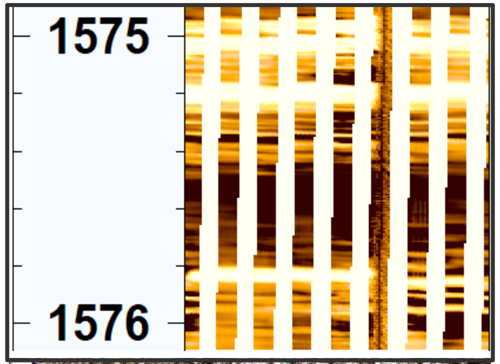


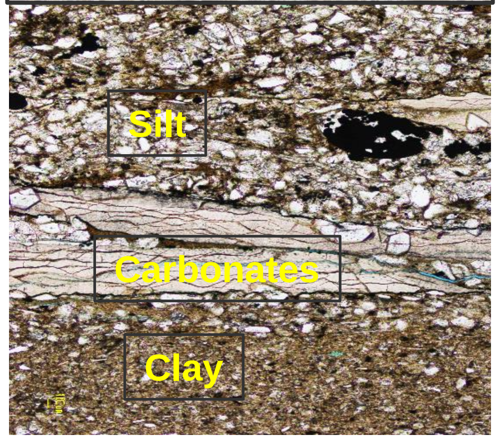




Key features:
- Massive black
- Trilobites
- No sedimentary feature

Heterolithic Shale (HSh)





Key features:
- Heterolithic beds
- Wave ripples cross laminations
- Partly bioturbated

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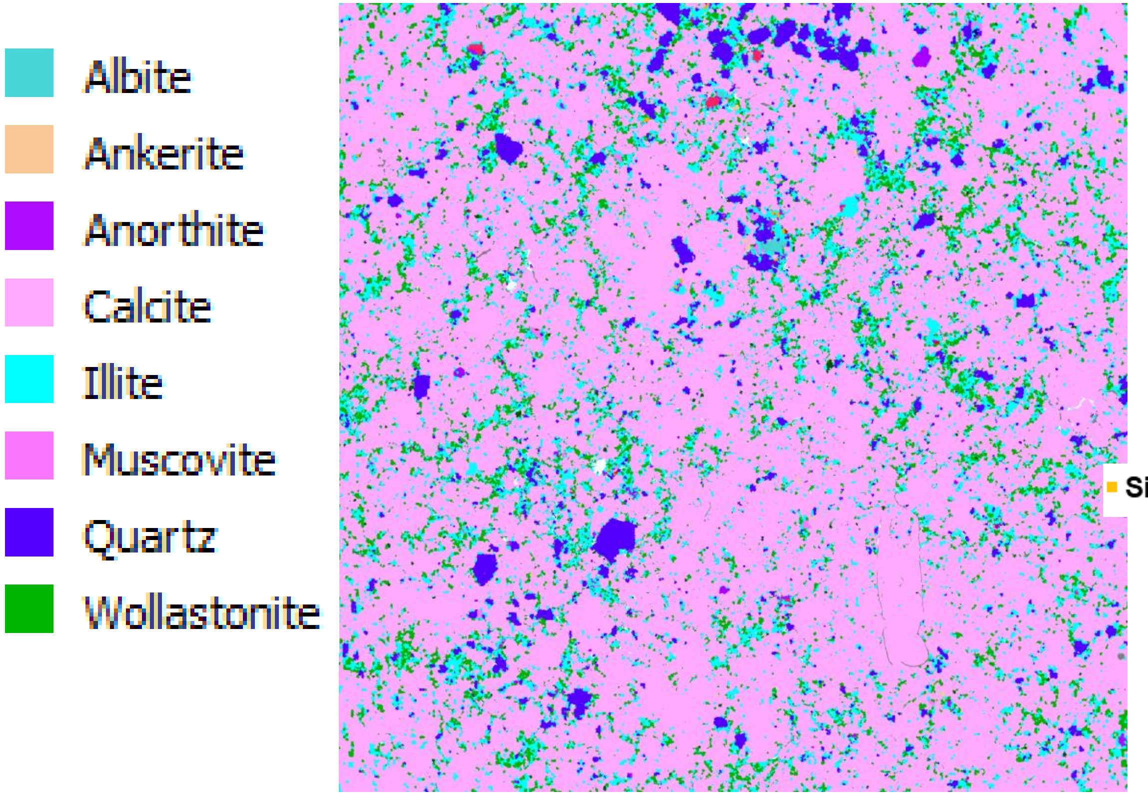
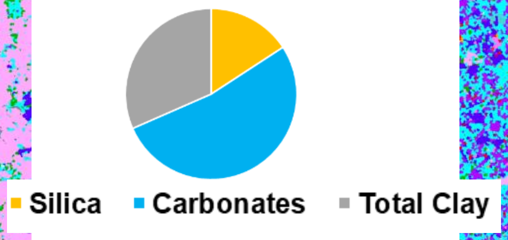
Mineral distribution mapping – High resolution (1 micron) TIMA analysis

High resolution TIMA helped to differentiate mineralogy, pore spaces/size, grain size and grain to grain contacts.

TIMA Ø = 3.92%

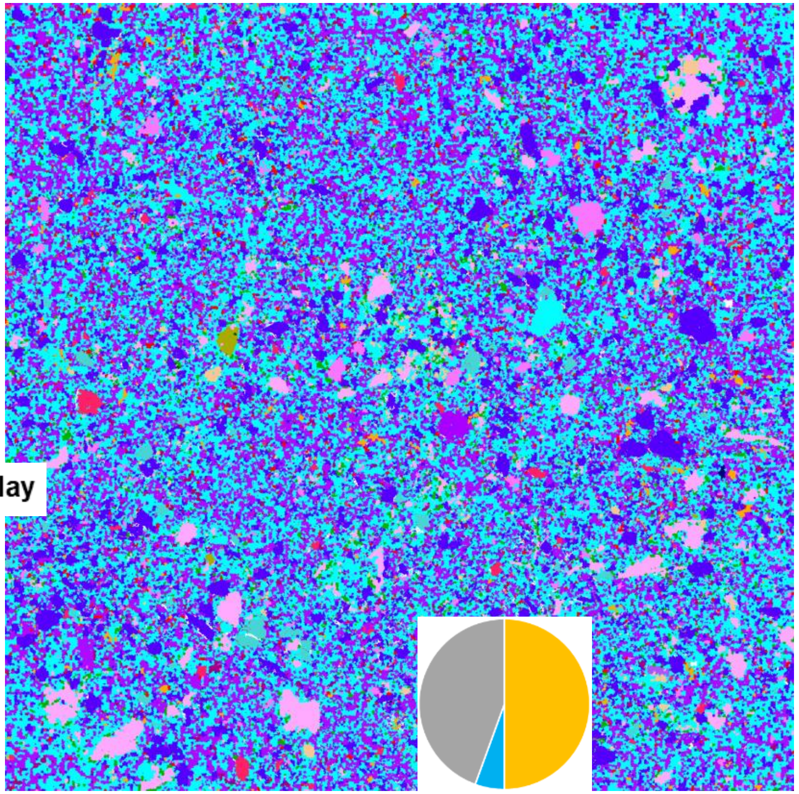
Concretionary-banded Shale (CSh)





TIMA Ø = 3.16%

Thinly Laminated Shale (TLSh)



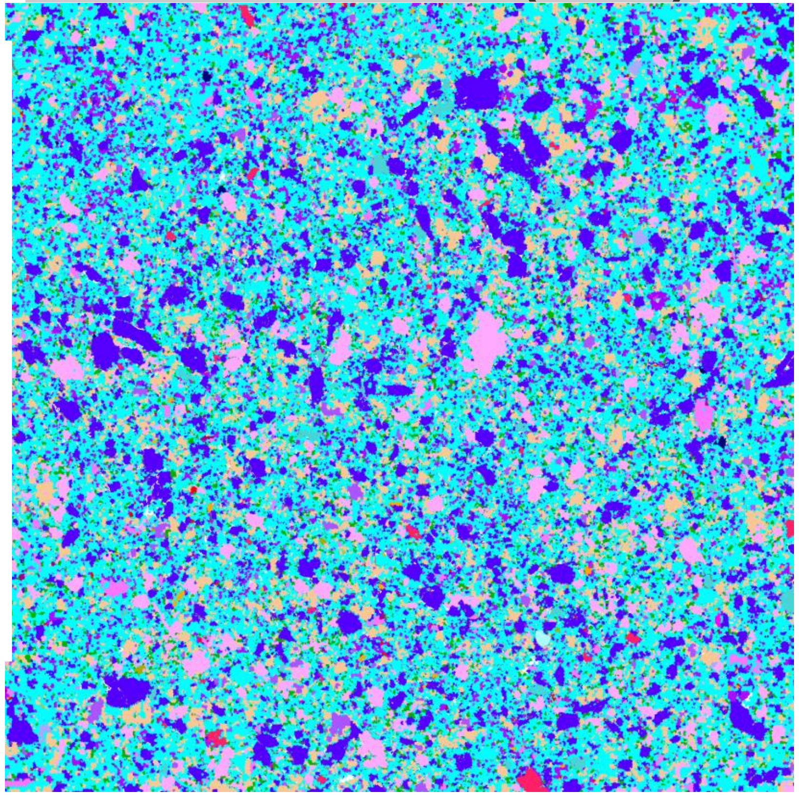
Mineral distribution mapping – High resolution (1 micron) TIMA analysis

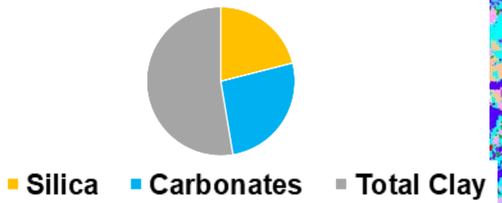
High resolution TIMA helped to differentiate mineralogy, pore spaces/size, grain size and grain to grain contacts.

TIMA Ø = 6.20%

Massive Black Shale (MBSh)

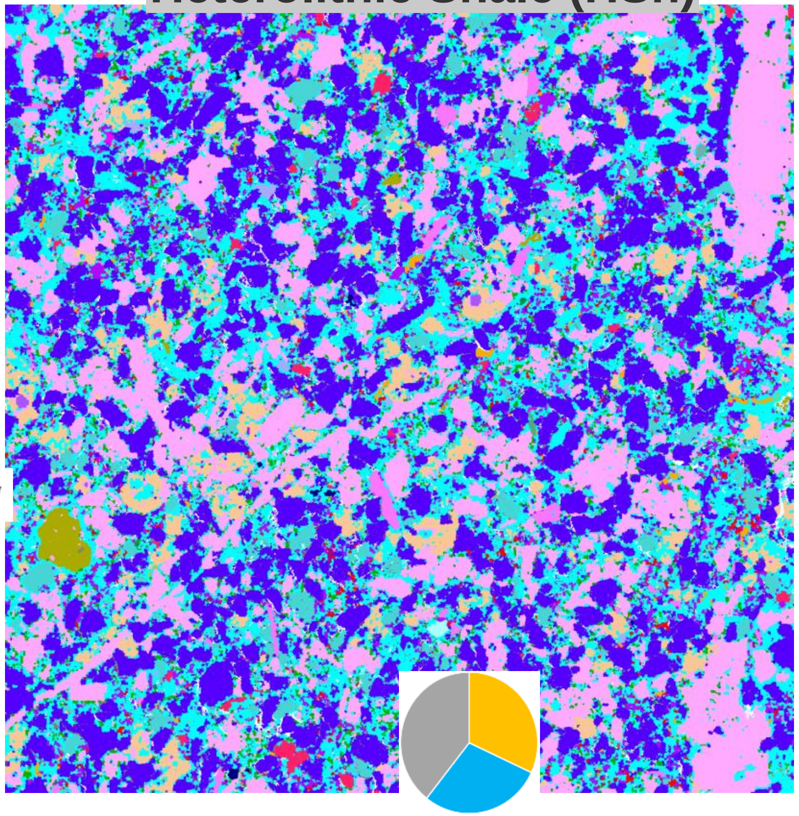
- Albite
- Ankerite
- Anorthite
- Calcite
- Illite
- Muscovite
- Quartz
- Wollastonite





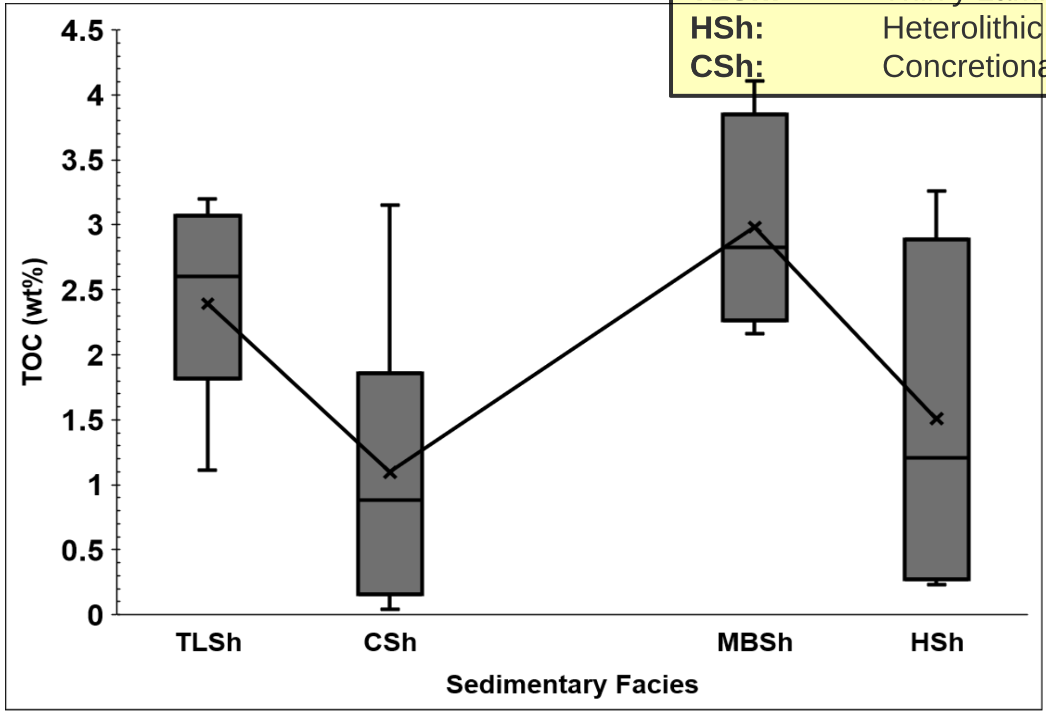
TIMA Ø = 6.53%

Heterolithic Shale (HSh)



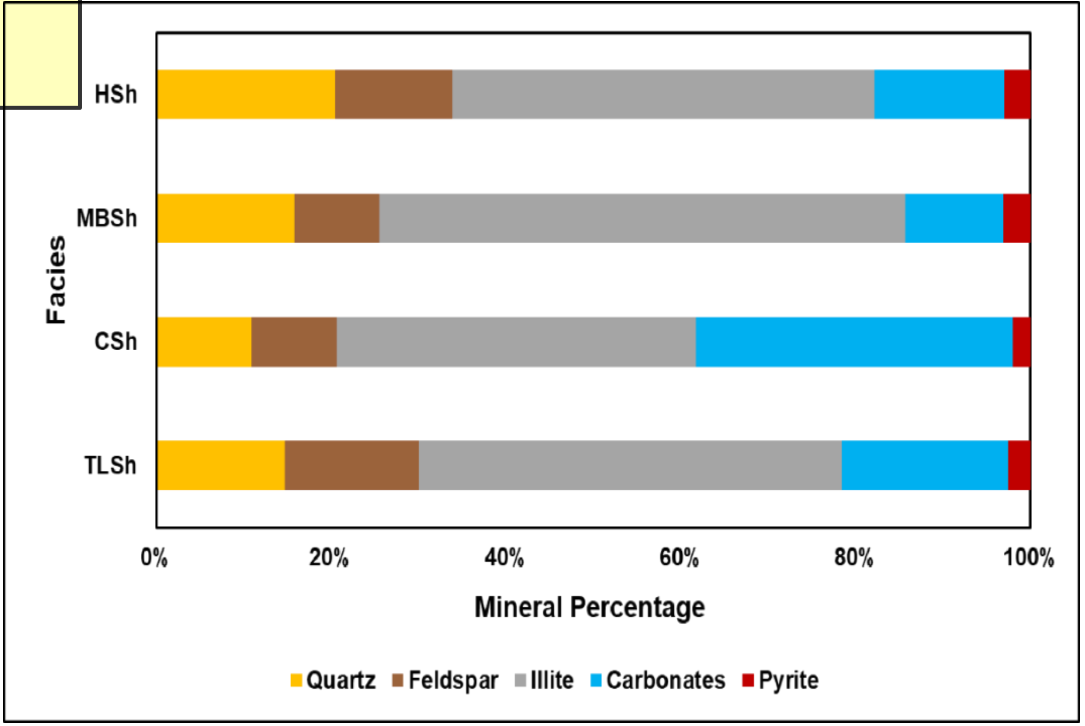
Results and Discussion

TOC (wt%)



MBSh: Massive Black Shale
TLSh: Thinly Laminated Shale
HSh: Heterolithic Shale
CSh: Concretionary-banded Shale

XRD Mineralogy (wt%)



Key points:

- TOC varies with sedimentary facies e.g. MBSh has highest TOC and CSh has lowest.
- Heterogeneties exist in mineral compositions.
- All facies are illite rich.
- HSh and TLSh have highest silica minerals (quartz+feldspar).

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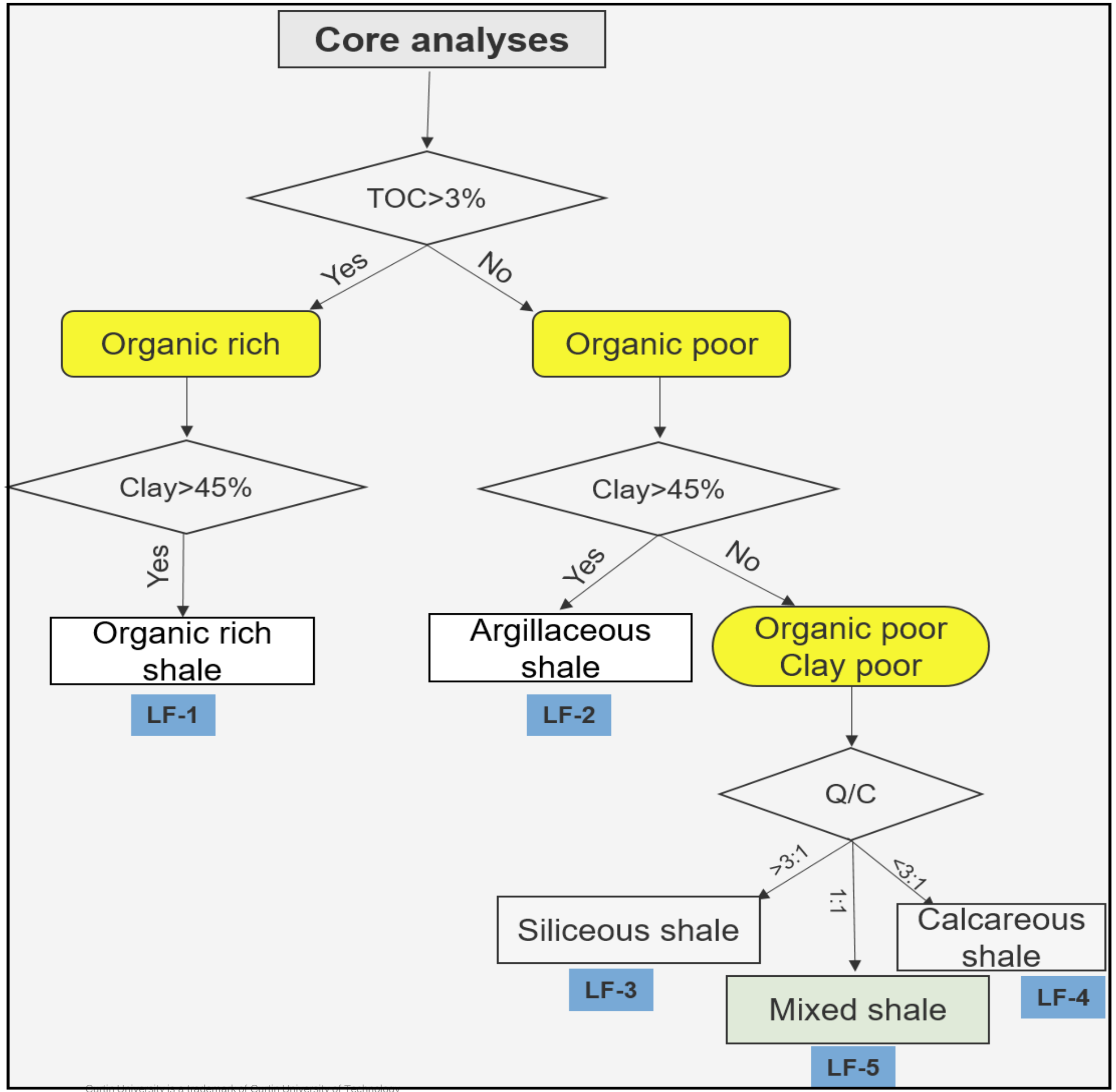
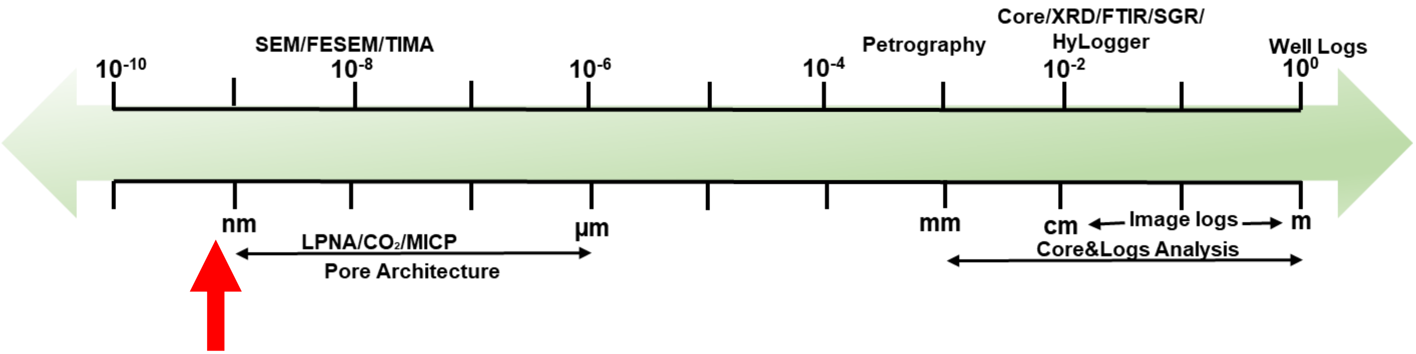
Lithofacies classification scheme



- LF1: Organic rich shale
- LF2: Argillaceous Shale
- LF3: Siliceous Shale
- LF4: Calcareous Shale
- LF5: Mixed Shale

Part – 2: Pore morphology and structure



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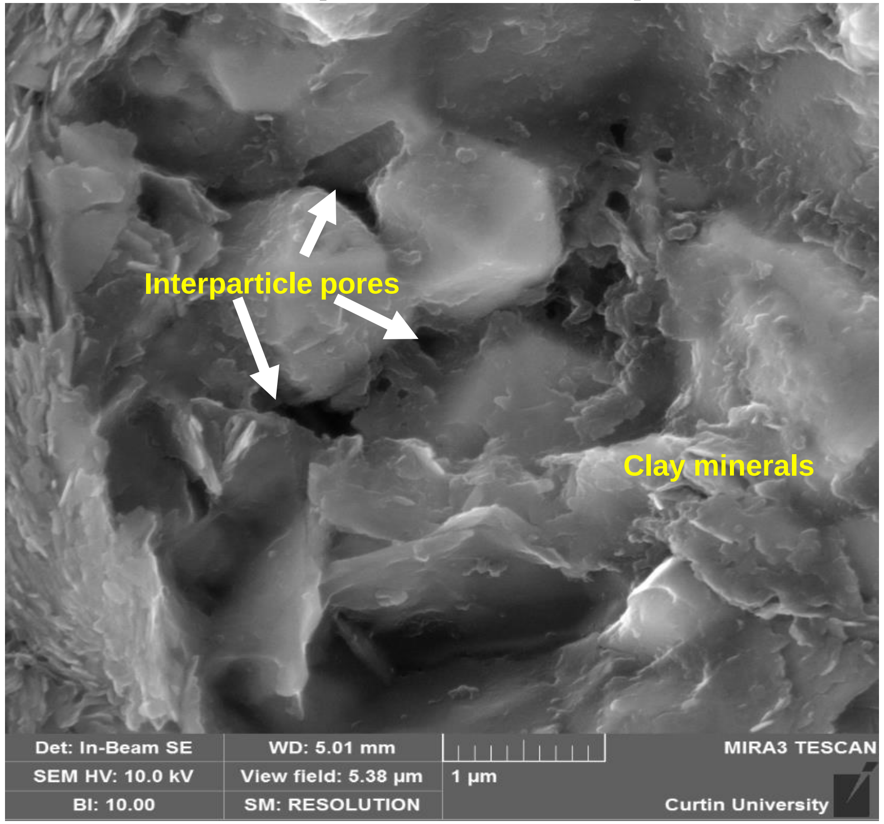
Part 2a: Pore types and morphology – FESEM analysis

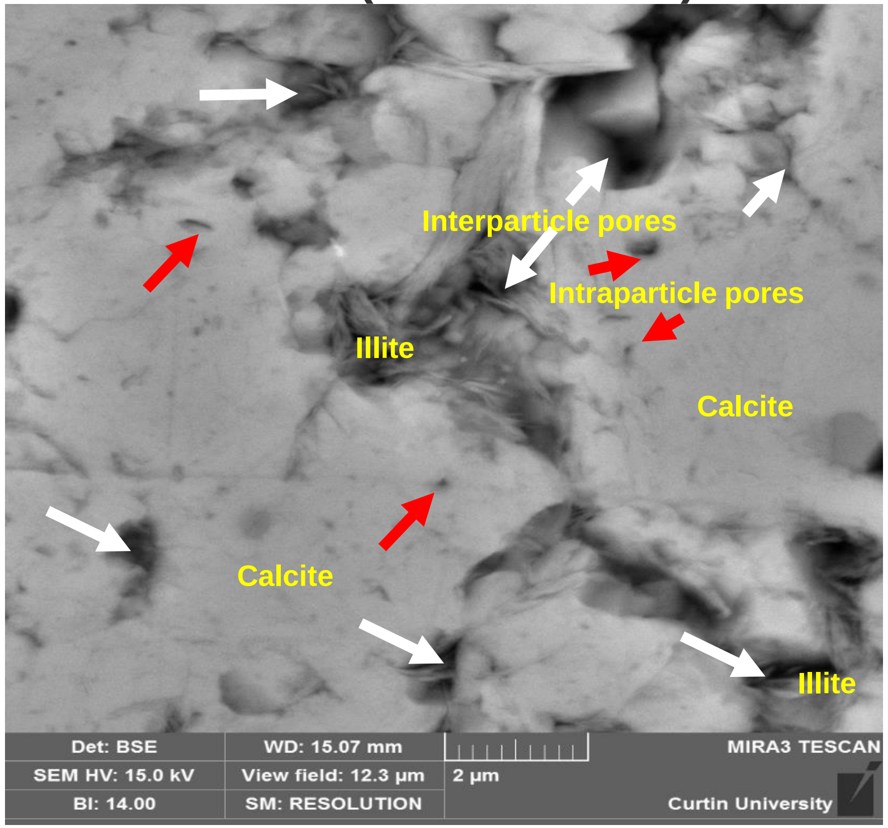
Key points:

- TLSh – Interparticle pores, connected.
- CSh – Inter- and Intraparticle pores, illited filled, poorly connected.

TLSh (TOC: 2.5 wt%)



CSh (TOC: 0.6 wt%)



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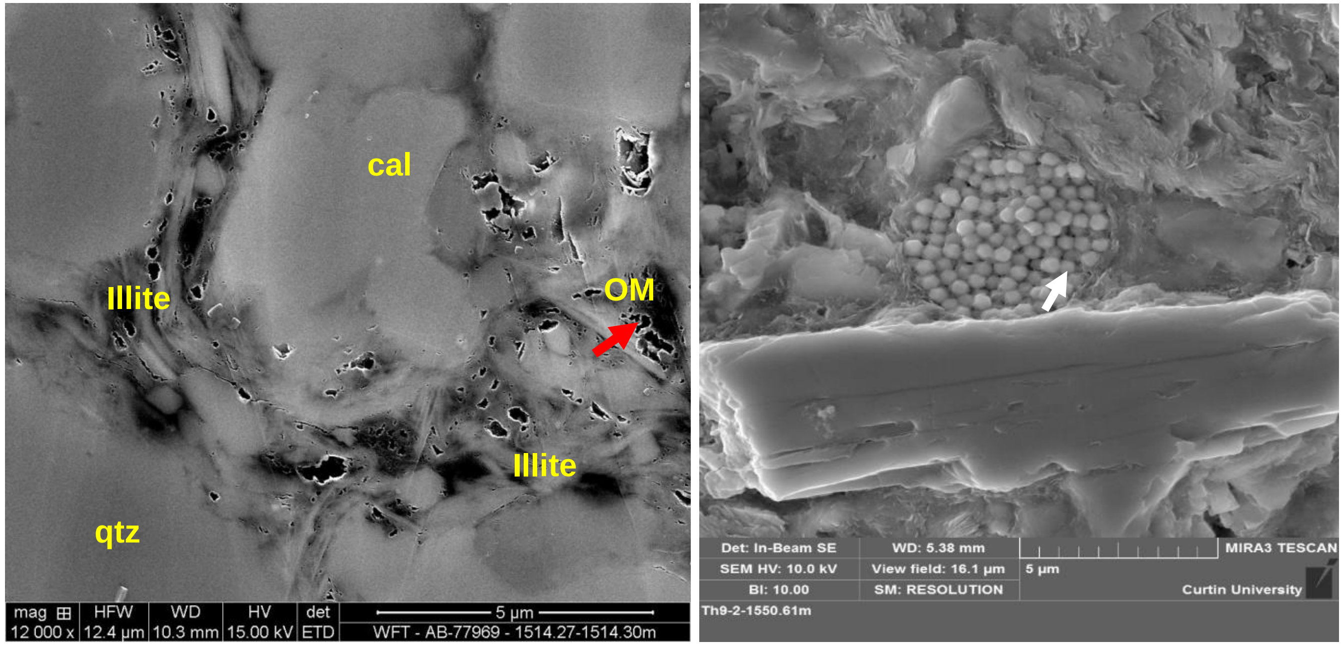
Part 2a: Pore types and morphology – FESEM analysis

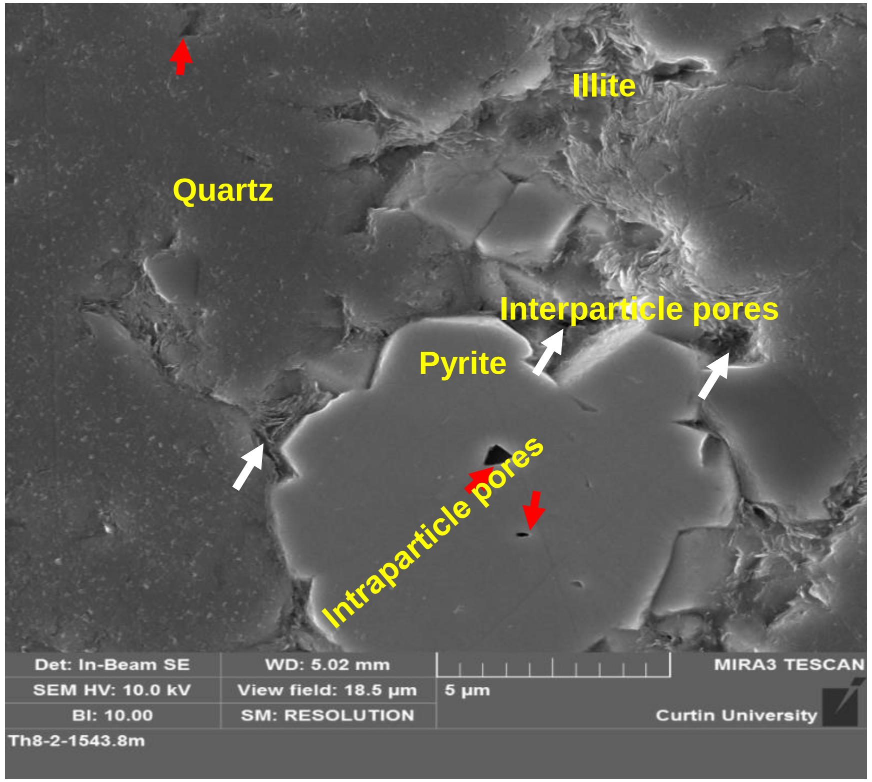
Key points:

- MBSh – Nano-pores in organic matter, Interparticle pores, connected.
- HSh – Inter- and Intraparticle pores, illited filled, poorly connected.

HSh (2.16 wt%)

MBSh (TOC: 4 wt%)





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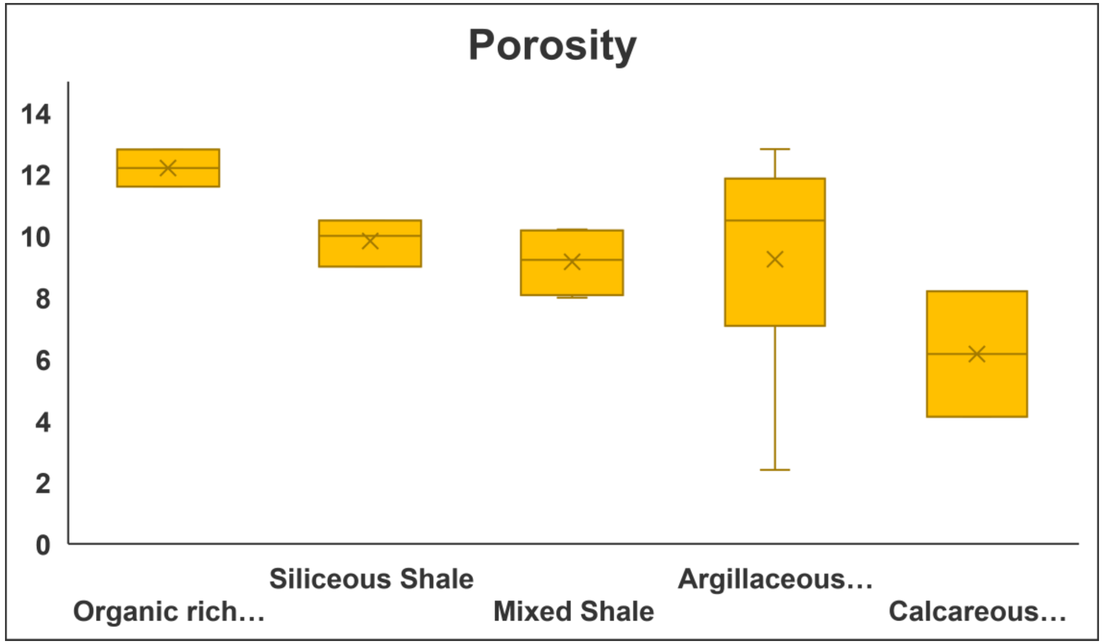
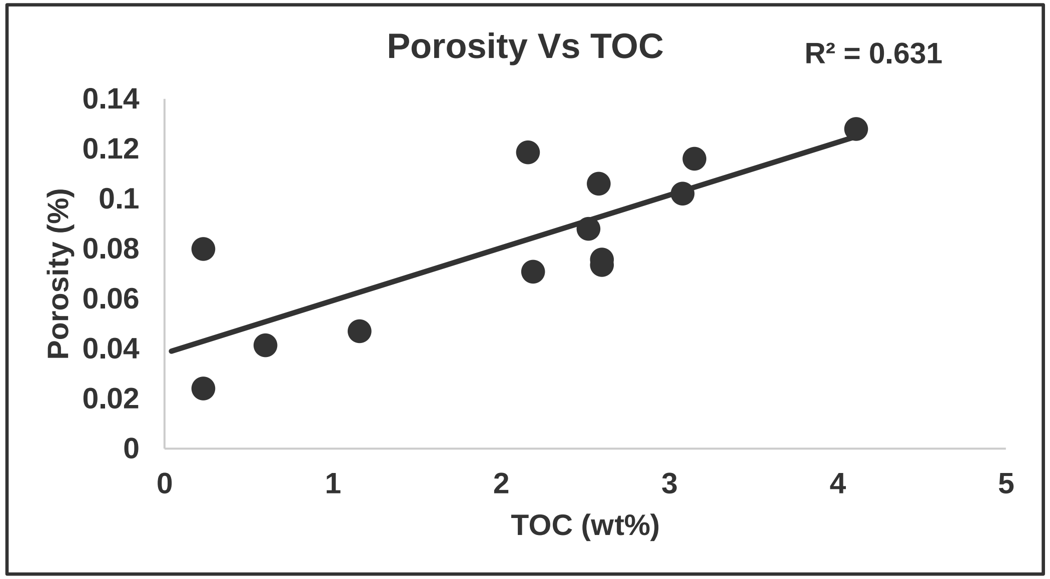
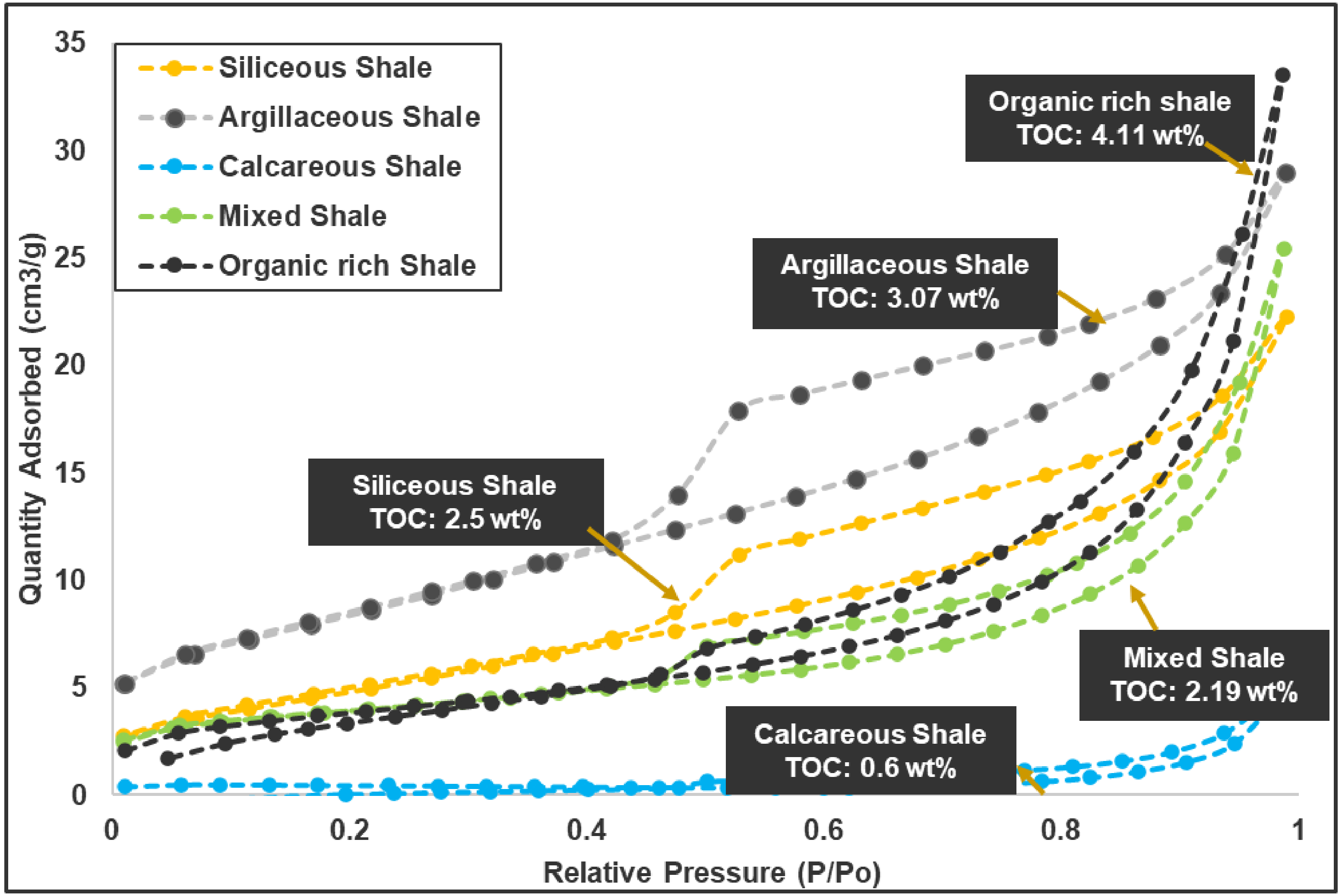
Part 2b: Porosity – Crushed sample



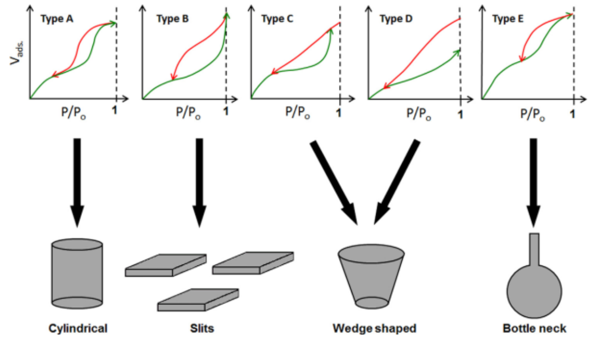


Part 2c: Pore Structure – LPN2 adsorption



Key points:

- Cylindrical and slits pores – **MBSh and TLSh**
- Slits pore – **MBSh**
- Cylindrical pores – **HSh**
- Wedge shaped pores – **CSh**



De Boer 1958

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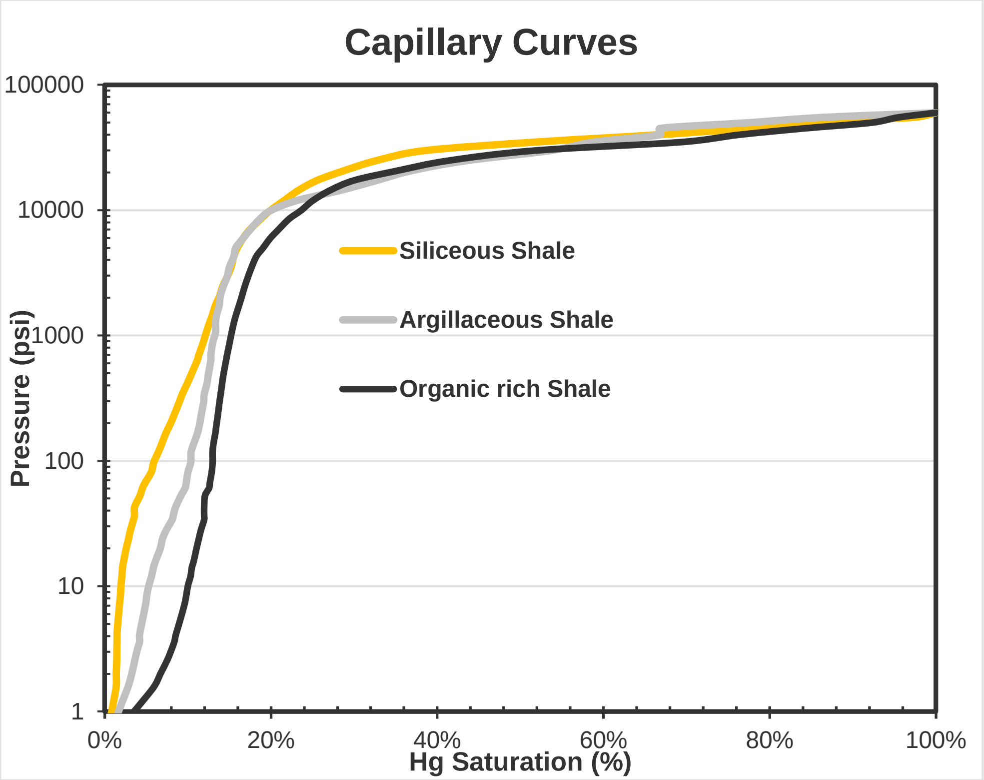
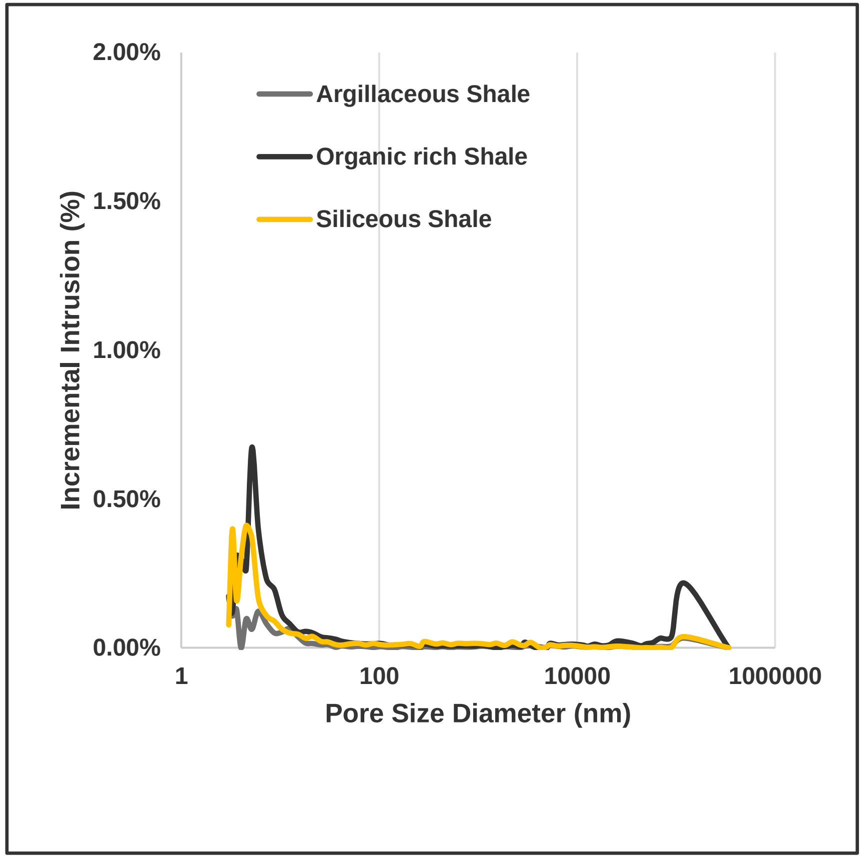
Part 2d: Capillary curves and PSD – MICP





Key points:

- Type 1: Unimodal, uniform- Organic rich, Argillaceous and Siliceous Shales
- Type 2: Bimodal, non-uniform - Mixed Shale
- Type 3: Bimodal, uniform - Calcareous Shale

MICP/liquid pyknometry (He) pore volume ratio:

Org. rich shale = **0.85**, Sili. Shale = **0.7**, Arg. Shale = **0.45**, Cal. Shale = **0.4**, mixed shale = **0.2**

Connected pores: org. rich, sili, and some Arg. Shales; **non-connected**: Calc and mixed shales

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Conclusions and Recommendations/Future Work

A multiscale analytical approach helped us to conclude that:

- The Goldwyer-III shale consists of massive black shale and shale with thin silt, carbonate, clay laminae, or bands.
- The mesopores are mainly in the inorganic grains while the micropores are primarily in the organic matter.
- The massive black shale bands, with higher average TOC of about 3.6% have high proportions of intergranular, intragranular and organic matter pores.
- Overall petrophysical rock typing suggested the producibility:

  MBSh (Organic rich shale) > TLSh (Siliceous) > HSh (Mixed) > Calcareous shale.

- It is highly recommended to understand the distribution of producible and brittle layers in Goldwyer-III shale across the Canning Basin.
- To measure the adsorbed gas content to estimate the reserves accurately.

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Department of Mines, Industry Regulation and Safety

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