Pore Typing Workflow for Complex Carbonate Systems*

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Abstract

Determination of Petrophysical Rock Types (PRTs) in carbonates is an industry recognized best practice for reservoir characterization. However, current methods fail to capture factors such as diagenetic modification, multimodal pore throat distributions, fractures, and integration of dynamic data. This article discusses the inclusion of pore throat distributions in the pore typing step which is an integral element of the PRT workflow developed in Chevron, accounting for different data scenarios depending on availability of core, MICP and logging data.

Carbonate petrophysical heterogeneity is generally the result of complex and multi-modal pore systems, including fractures. Carbonate pore systems in subsurface reservoirs that have seen even mild diagenetic overprint can rarely be decomposed into contributions from end-member pore types based on syndepositional texture. Conventional rock typing methods use petrographic observations, including image analysis to determine pore types qualitatively or quantitatively in an attempt to relate the pore system, at least in part, to flow and textural pore types. However, such techniques more than often do not resolve the complexity and multi-modality of the pore system and result in a misrepresentation of dynamic properties as documented by examples.

Identification and prediction of pore types in the well bore from core and logs and their spatial prediction is therefore essential for a reliable rock typing in carbonates. Appropriate pore type identification comes from mercury porosimetry (MICP) interpretation. MICP is providing information on pore throat distributions controlling flow in reservoir. MICP derived pore types have to be combined with larger scale observations, such as vugs and fractures. Grouping pore throat modes from capillary pressure curves and mapping those on selected and representative porosity-permeability plug data provides a reliable way to predict pore type groups in multimodal systems and include the full scale of porosity from nanopores to macropores. MICP derived pore types have to be combined with larger scale observations, such as vugs and fractures, using specialty logs (e.g., NMR, FM) to provide this information.

The integration of MICP data in the pore typing step in carbonate rock typing optimizes the link between the different scales of (dynamic and static) observations but at the same time challenges the geologist to capture the spatial trends and relationships between resulting PRTs.

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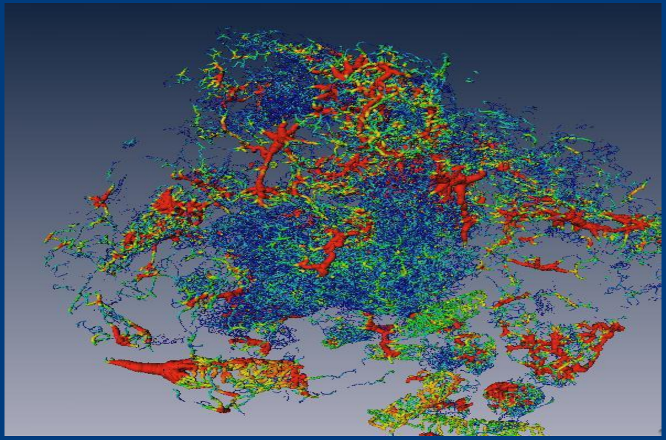
PORE TYPING WORKFLOW FOR COMPLEX CARBONATES



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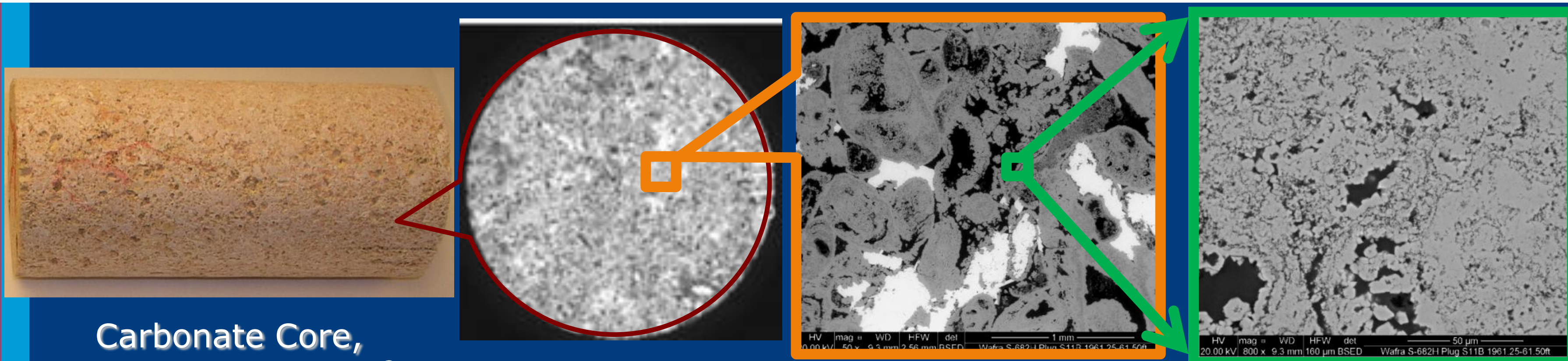
AGENDA

- Introduction; why pore types?
- Conventional pore type classifications
- Tools for pore type examination
- Pore type investigations in carbonates
- Pore Typing Workflow
- Conclusions

Pore Types

- Main control of the flow in Carbonates
- Linked to petrophysical models for permeability and water saturation
- Essential in Dual Porosity simulation
- Critical component of Petrophysical Rock Typing

Various scale pore systems: Carbonate multiscale images

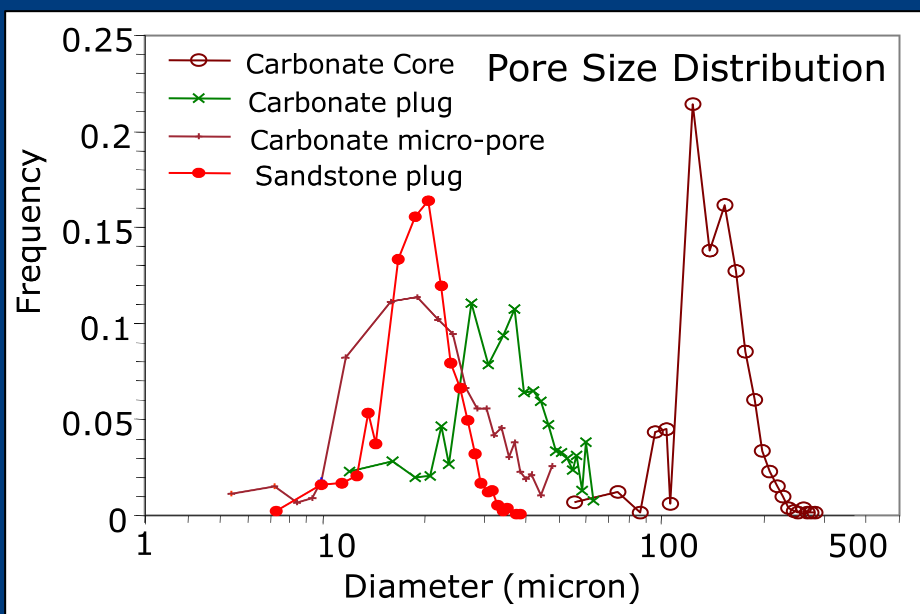


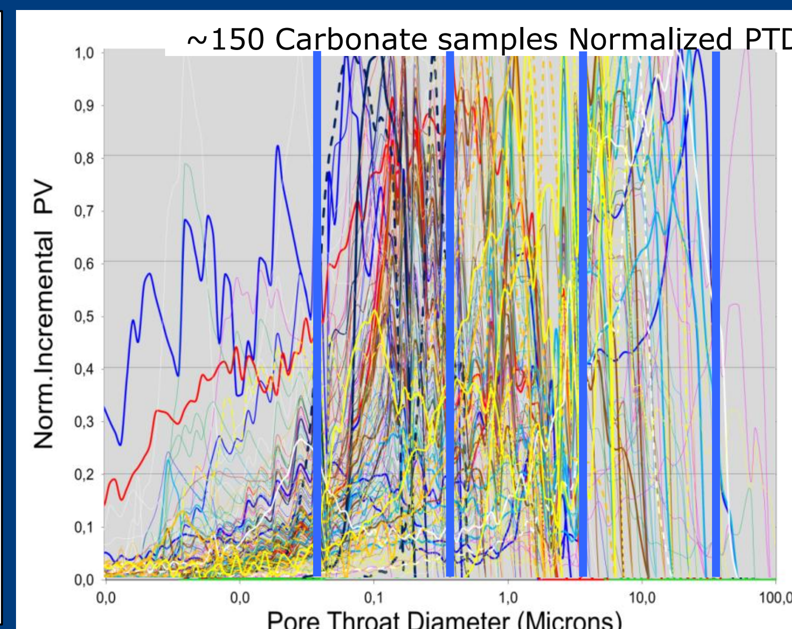
Carbonate Core, 2100x100x100 mm^3

Carbonate plug

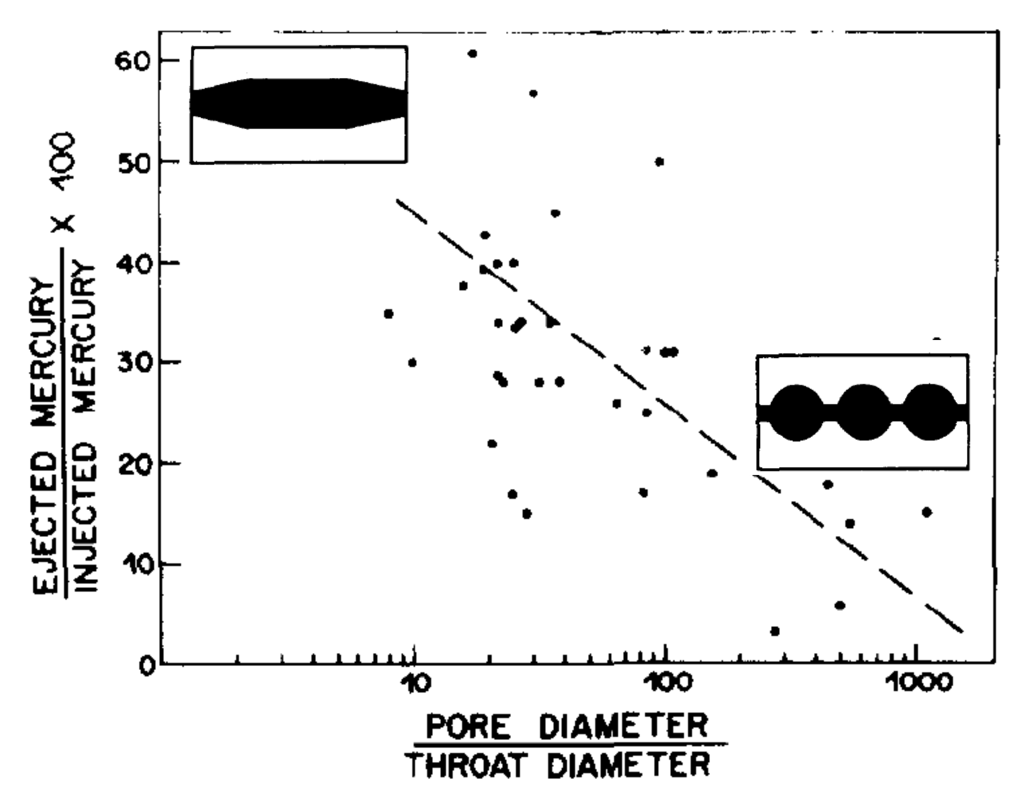
resolution = 1.25 micron

resolution = 0.077 micron

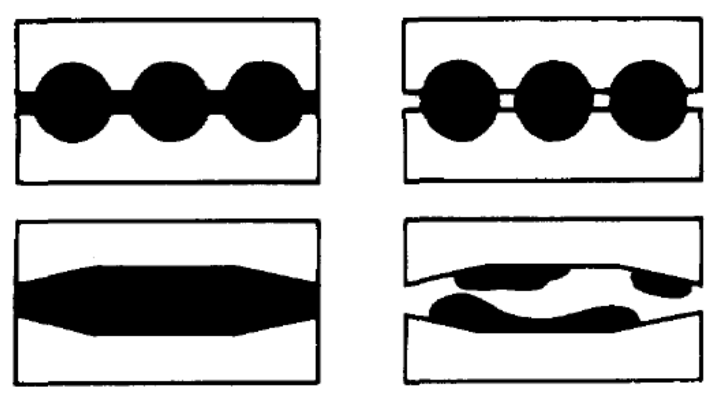




Pore size vs. pore throats



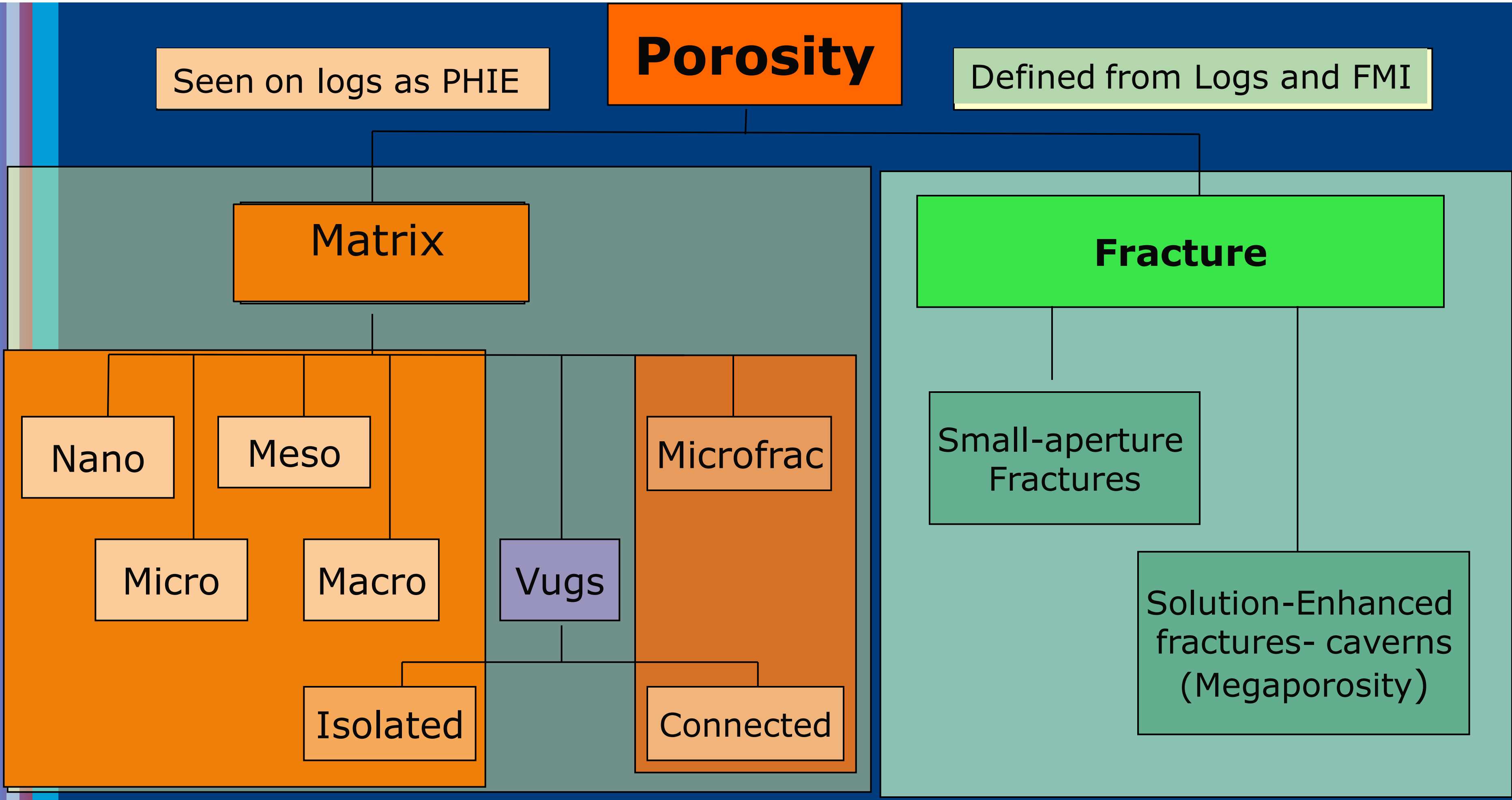
Mercury retention is higher for greater pore to throat size ratios



For crystalline dolomite fabrics higher ratio linked to higher retention and lower recovery

Modified after Wardlaw (1976)

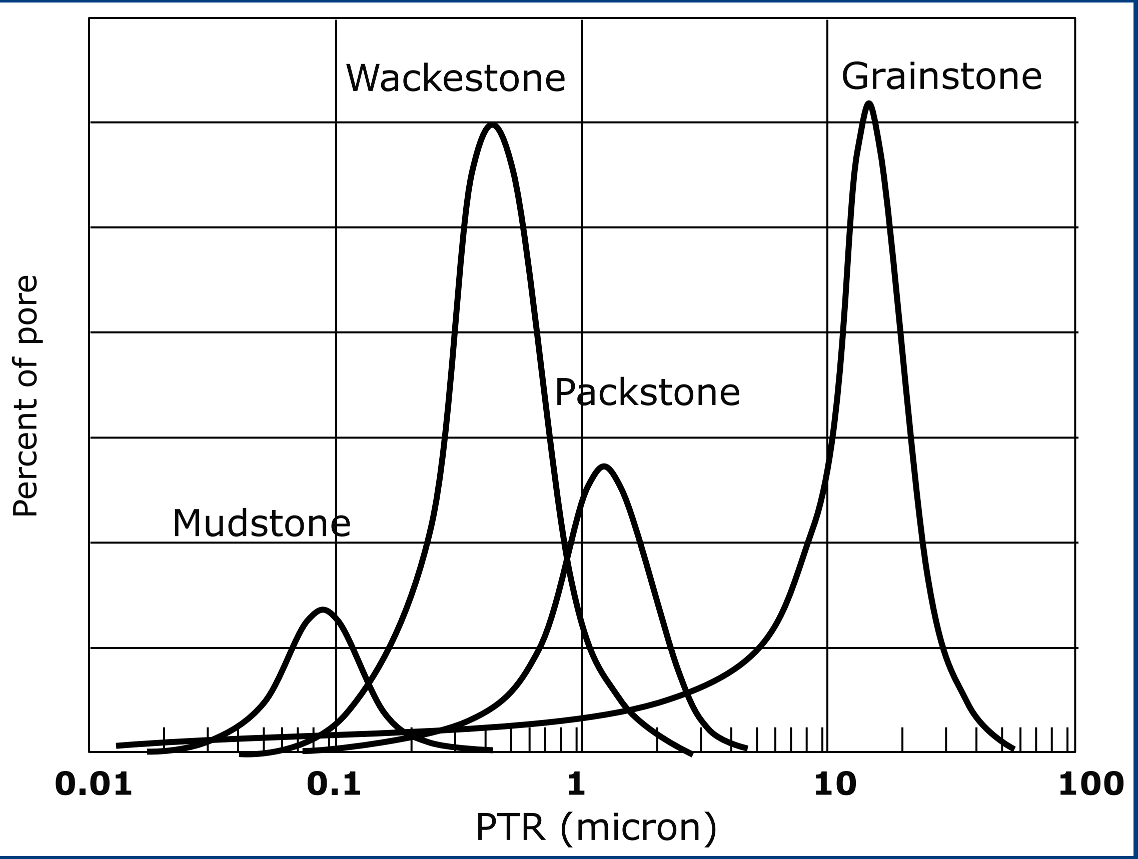
Dual Porosity Classification for Carbonates



Porosity Classification Systems – Overview

- Classic pore type classification systems mostly observational
- Archie (1952) – textural/petrophysical with 12 pore types
- Choquette and Pray (1970) – definitions of pore types genetic/depositional with 15 pore types
- Lucia (1983, 1995, 1999) – rock fabric/petrophysical with 18 pore types
- Lønøy (2006) – modified Choquette Pray pore size with 20 pore types
- Marzouk, Tazenaki, Suzuki (1998), Clerke et al. (2008) – MICP based

Pore Throat Size Classes



Macropores 1: Pore Throat size > 10 microns

Macropores 2: Pore Throat size between 4 and 10 microns

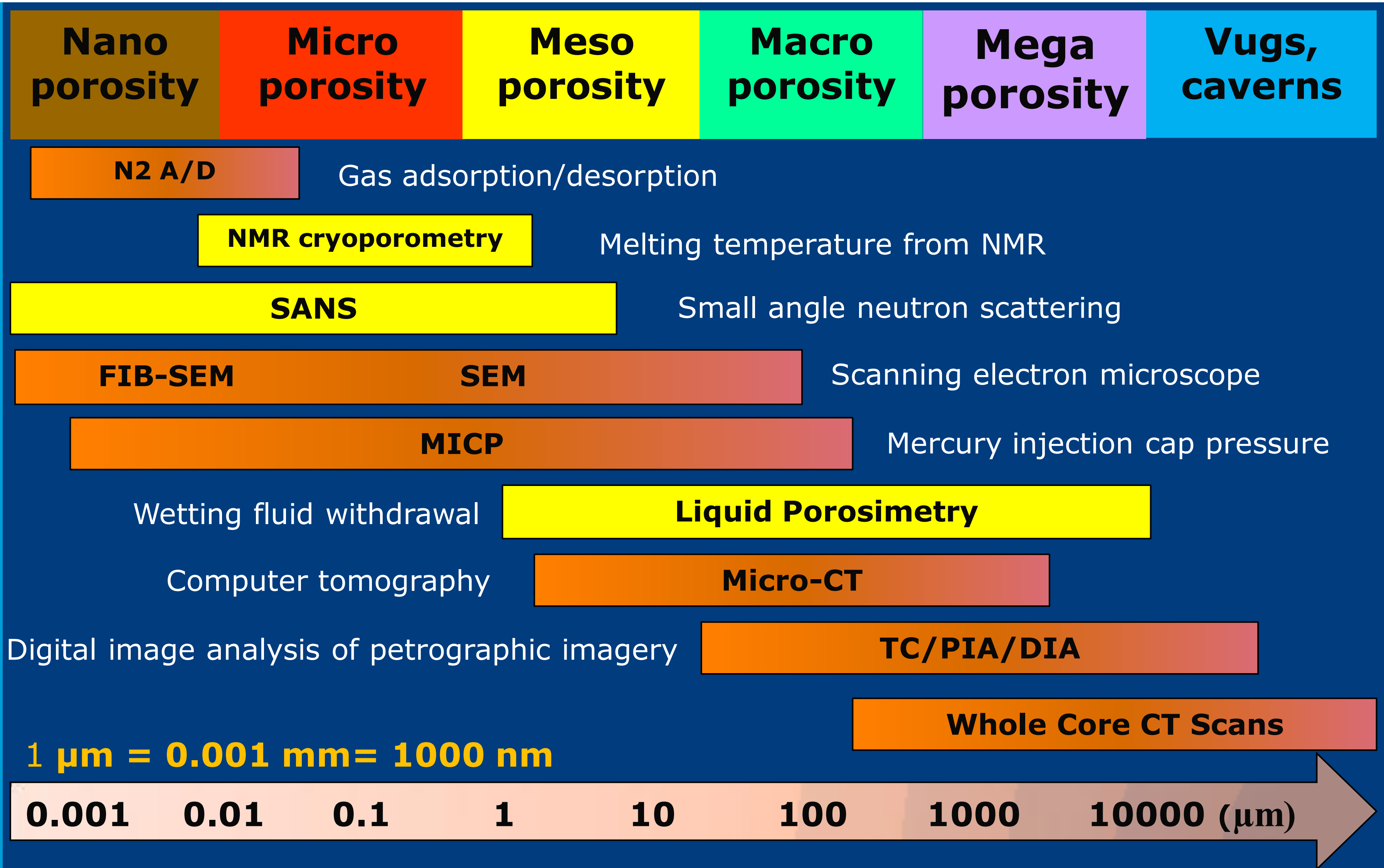
Mesopore 1: Pore Throat size between 1 and 4 microns

Mesopore 2: Pore Throat size between 0.3 and 1 micron

Micropore: Pore Throat size <0.3 micron

After Marzouk et al. (1995)

Core Based Pore Observation Tools vs. Scale



Microporosity Definitions

Observation: Microporosity definitions are driven by observation scale limits of specific tool

MICP — Pore throat size – [0.3 – 2] micron

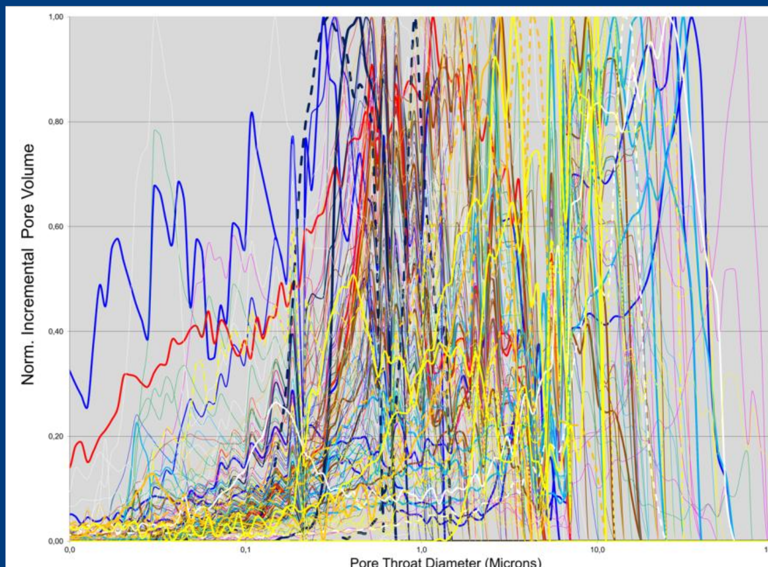
micro-CT — Tomography – [0.25 – 3] micron

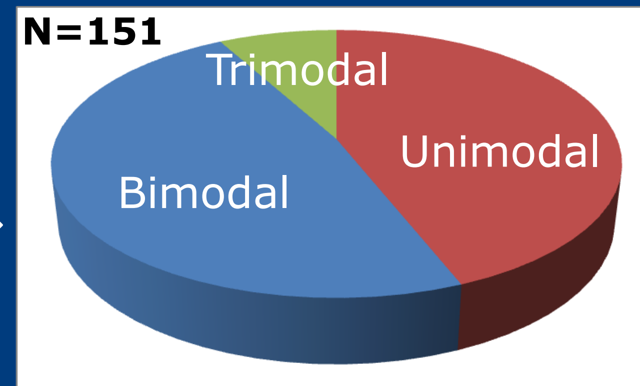
Fluid/Wettability — Water filled porosity – function of HAFW

TC — Thin sections – ~30 micron

0.1 | 1 | 10 | 100 (log micron)

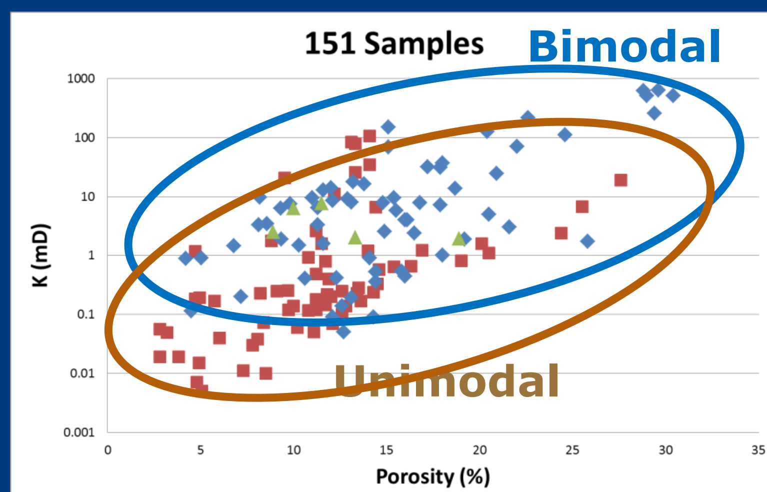
Devonian Carbonate Field Pore Types



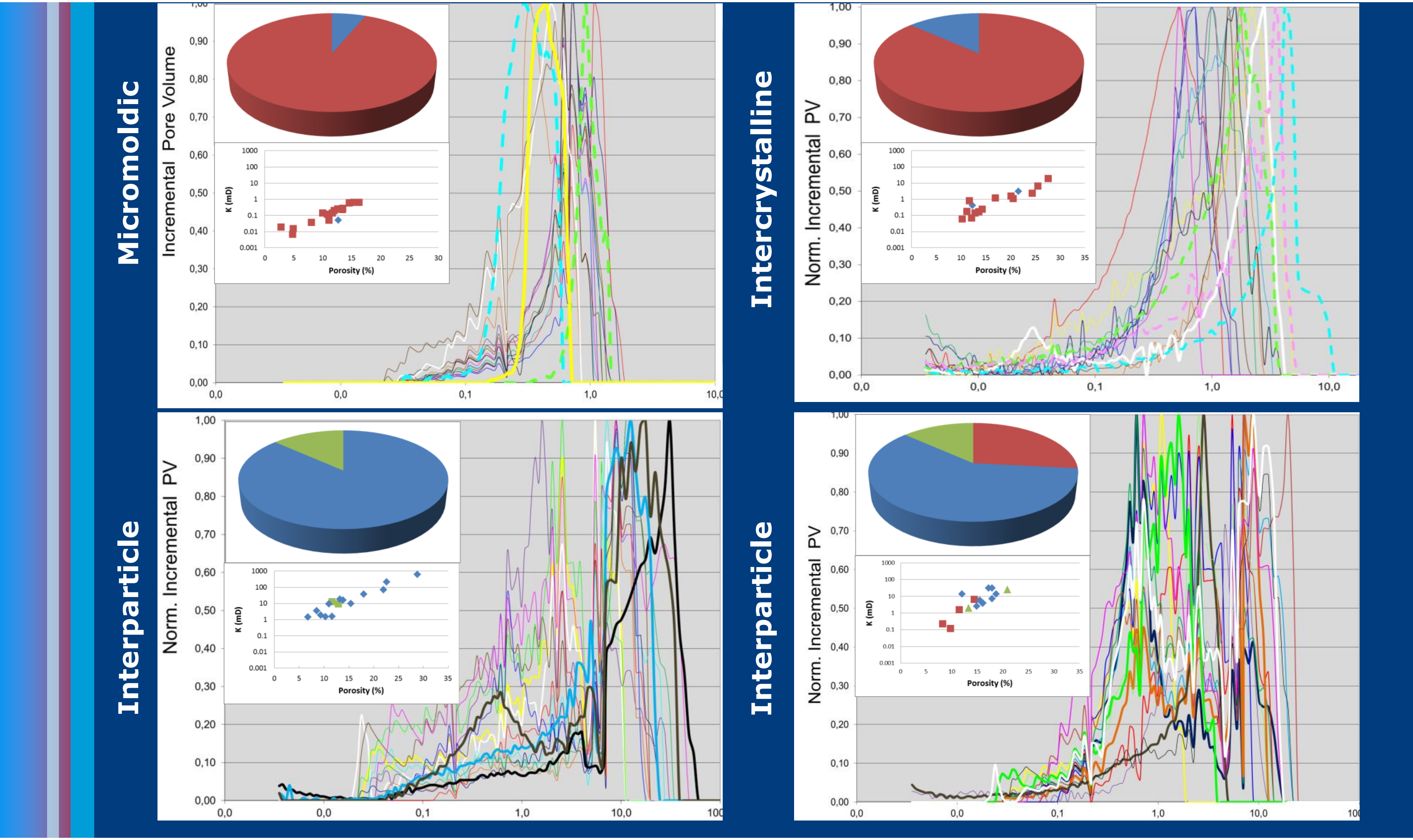


MICP Thomeer derived

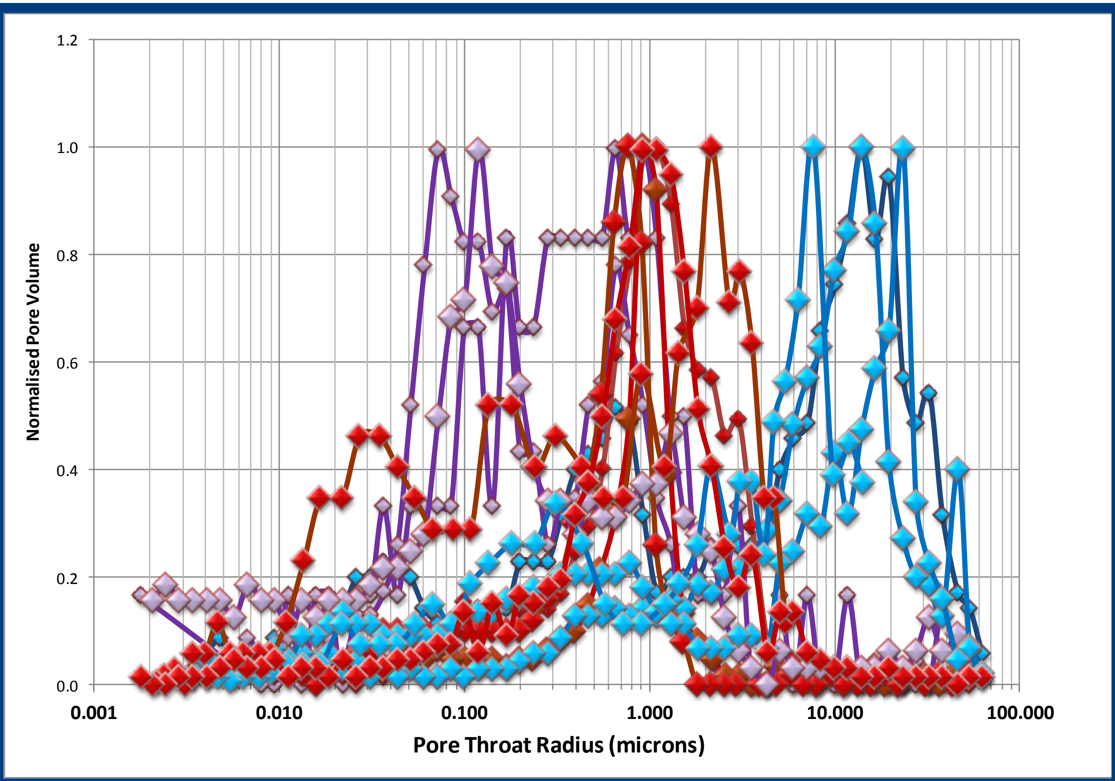
Pore types interparticle, moldic, intercrystalline

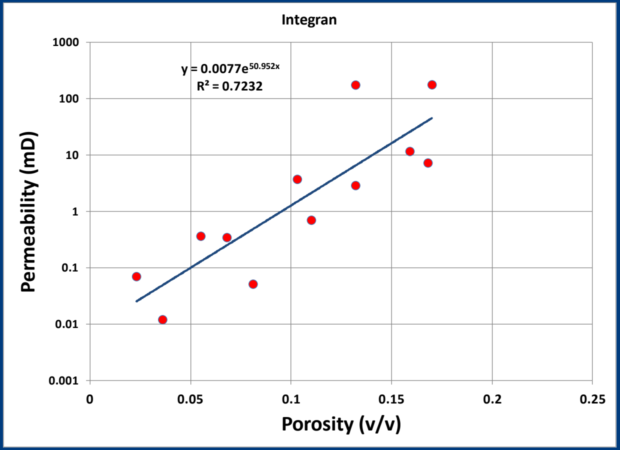


Devonian Carbonate Field – Lønøy Pore Types



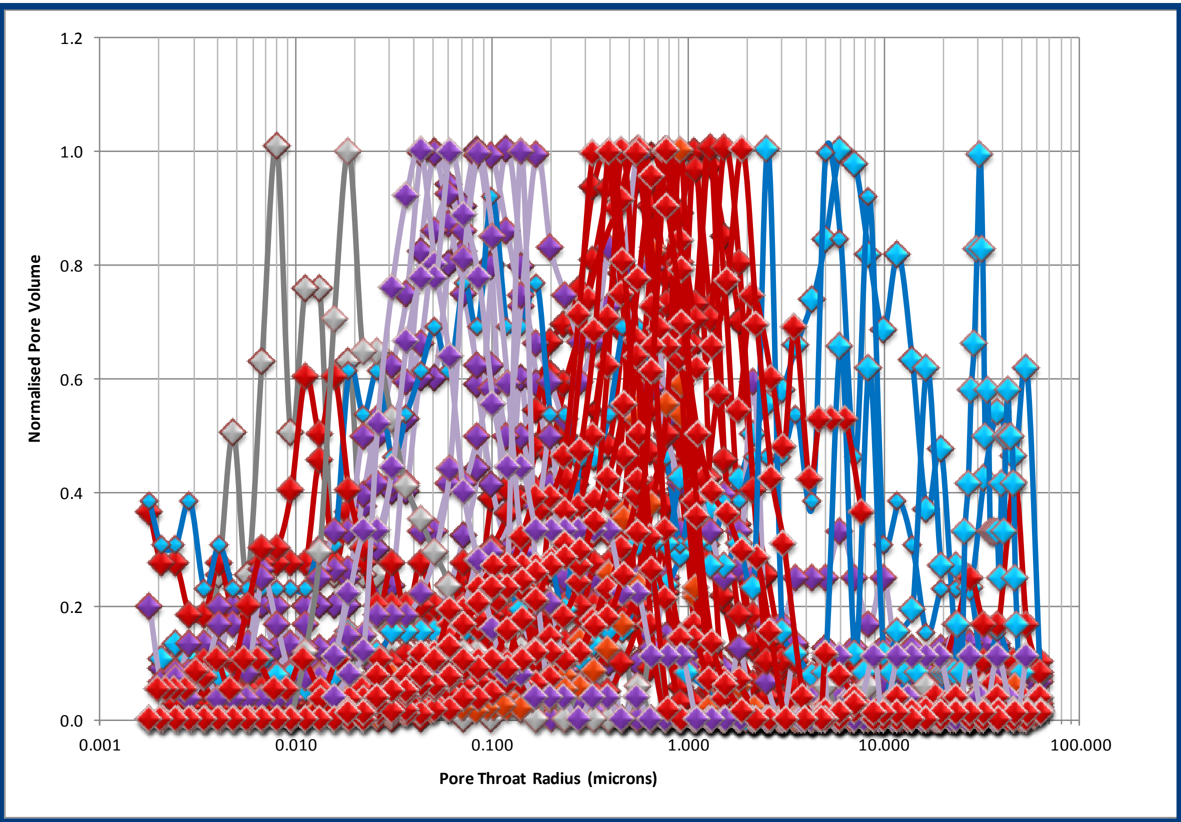
Carboniferous Field - Interparticle Porosity

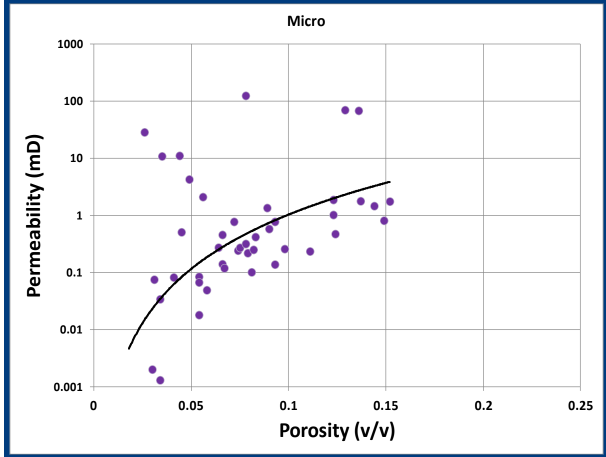




- Distinct phi-k trend in mostly unimodal pore throat systems
- Large range of permeability driven by pore throat size

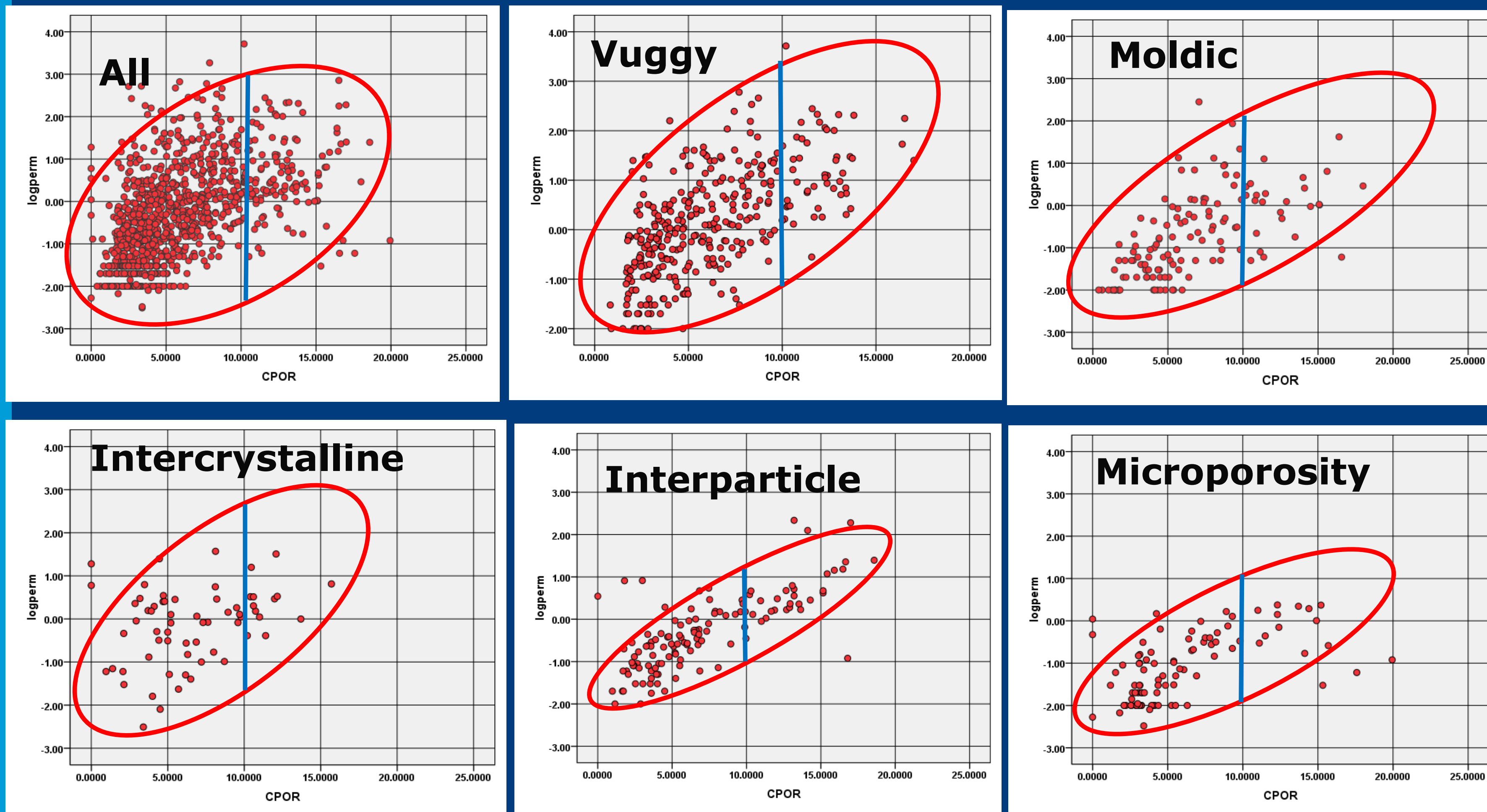
Carboniferous Field - Microporosity





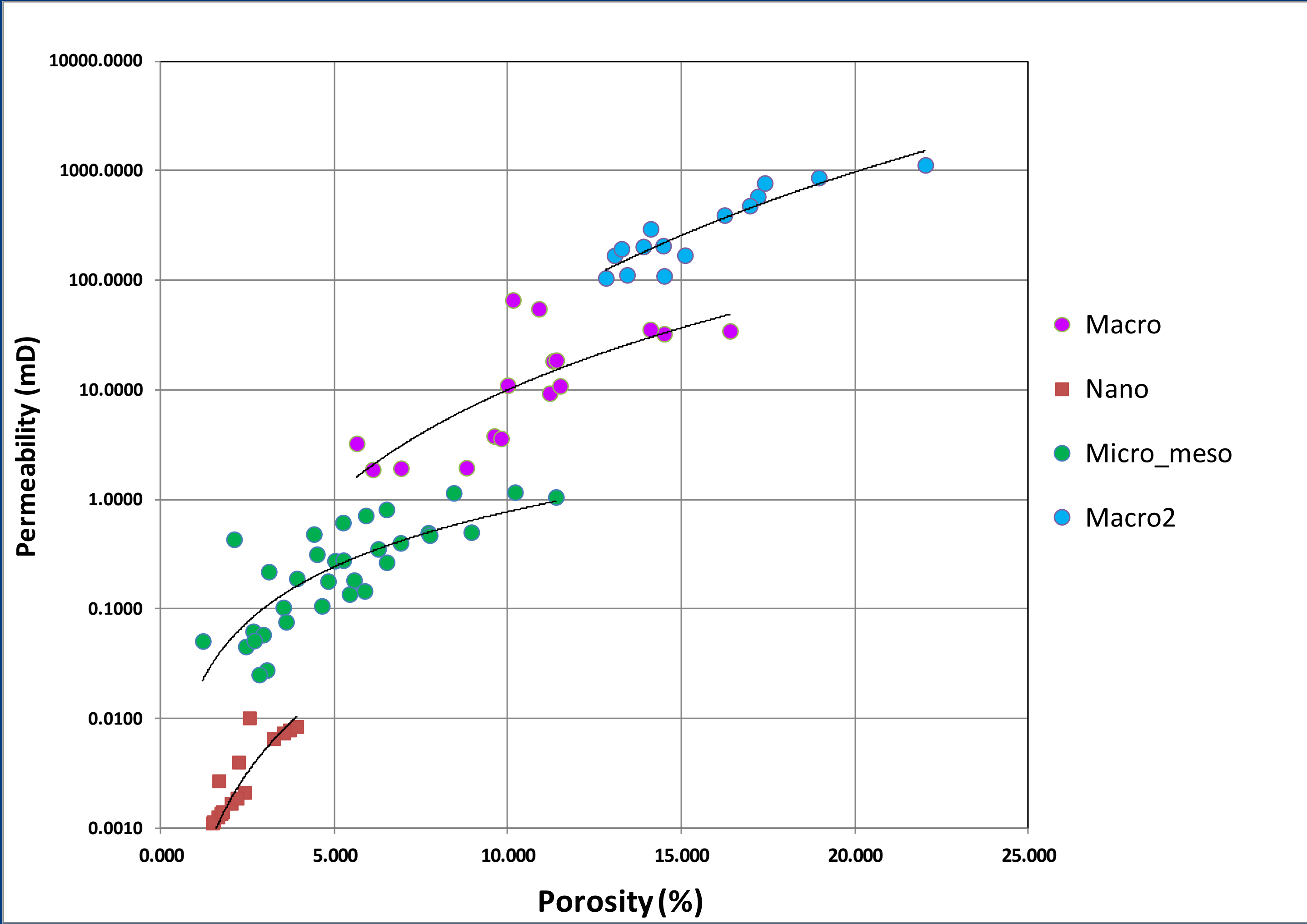
- Conventional (petrographic) classification as microporosity
- MICP shows multimodality of pore throats as well as mixture which confirms conventional classification is not adequate here

Cretaceous and Carboniferous Fields – Phi-K by Pore types

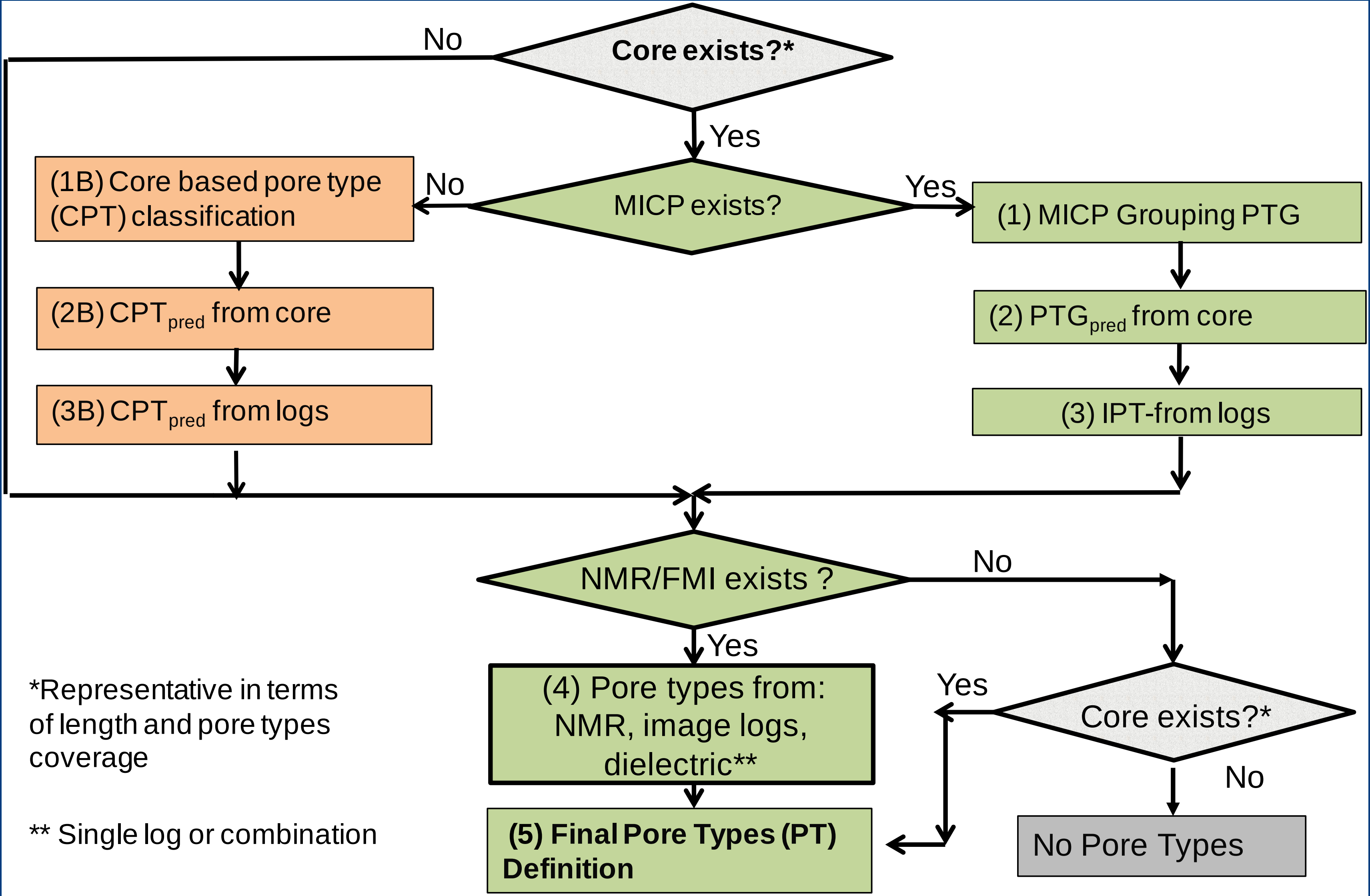


Conventional pore typing reduces perm uncertainty from 5 orders of magnitude (all) to 4 orders (vuggy, moldic, IC), 3 orders (microporosity) and 2 orders (interparticle)

Triassic Field - Phi- K by Pore Throat Size Classes



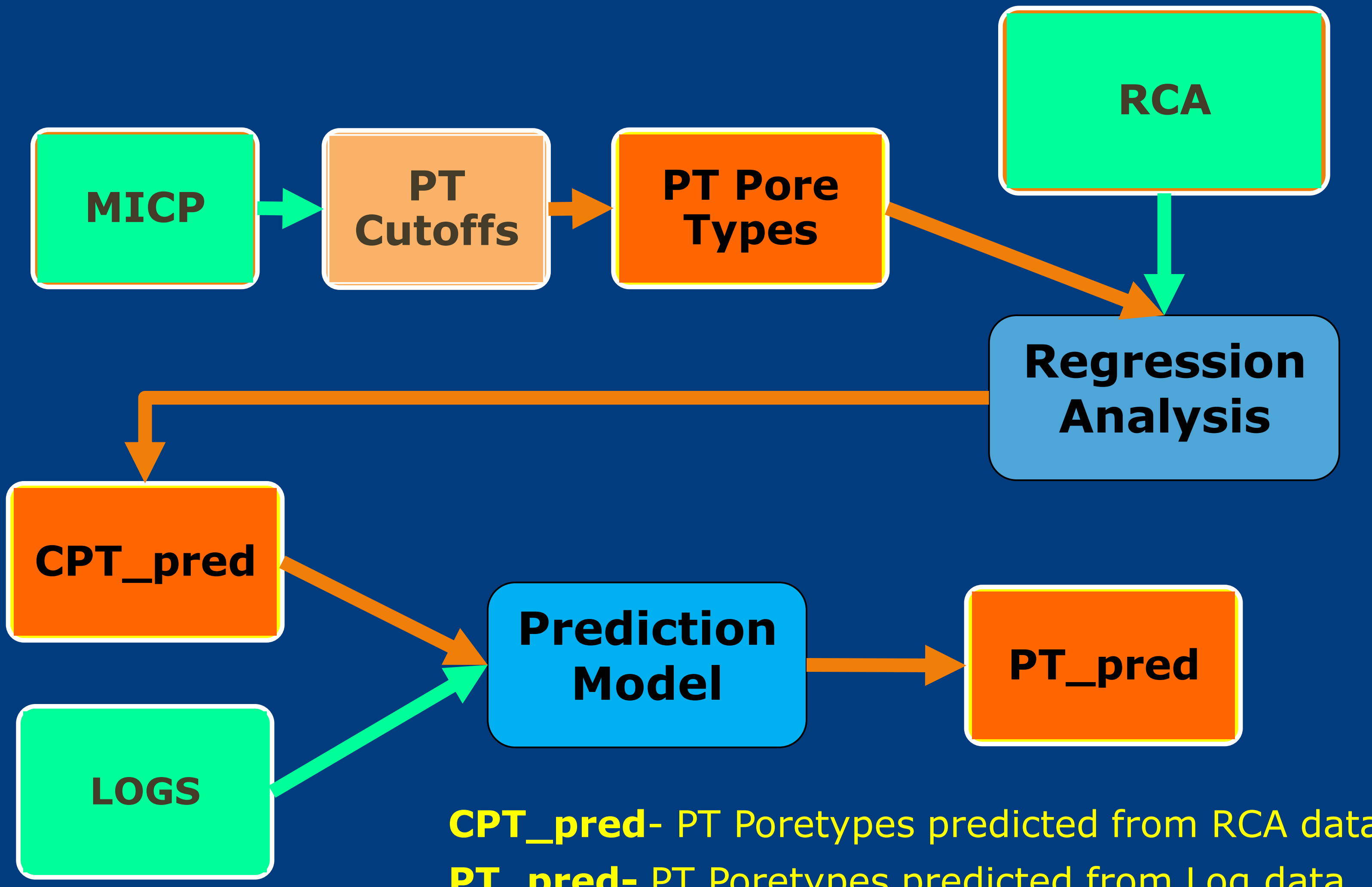
Pore Typing Workflow



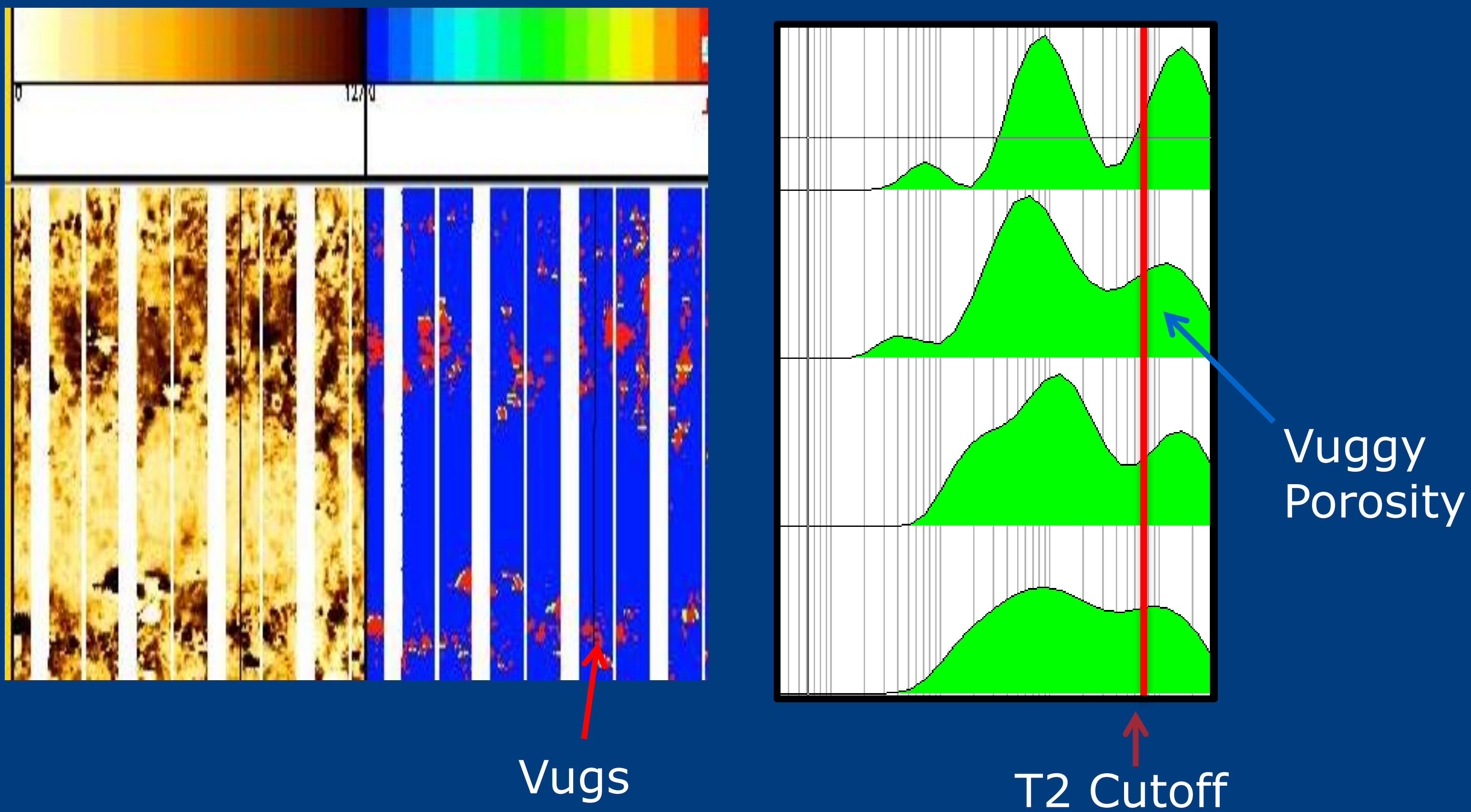
*Representative in terms of length and pore types coverage

** Single log or combination

Pore Type Prediction Workflow



Vuggy/Moldic Porosity form FMI & NMR



Conclusions

- Pore system investigation tools should cover full range of the pore size/throat scales; carbonates covers 7 orders of magnitude (nano to cm scale)
- Conventional pore typing methods often fail due to the weak link to geology and/or flow properties in bigger scale
- The proposed pore typing workflow integrates different scales and can accommodate different data scenarios
- Pore type definitions should be linked to dynamic/flow properties and geological processes