http://czqin.github.io

InterPore China Chapter 2026, 12-15 July, Suzhou, China

Characterization and Modeling of Porous Media for Sustainable Subsurface Energy Applications

Characterization of multiscale pore structures and multiphysics multiscale numerical modeling

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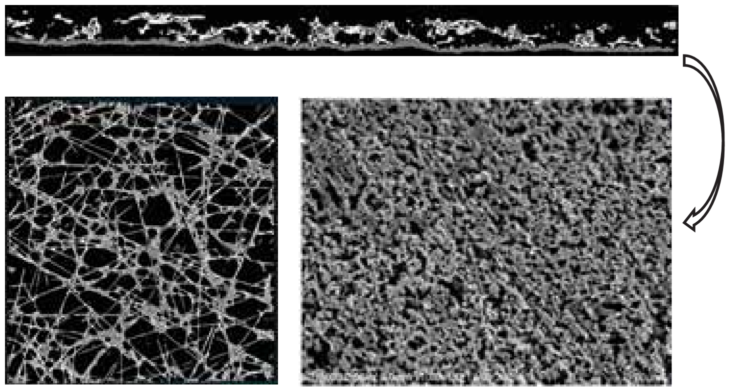
研究学术 造就人才 佑启乡邦 振导社会

Outline

1. **Multiscale pore structures** (shales, tight sandstones, carbonate rocks, etc.)
2. **The pore-network-continuum modeling** (motivation, mesh coarsening, verification)
3. **An empirical model for permeability of clay-bearing sandstones** (applications)
4. **Summary and outlook**

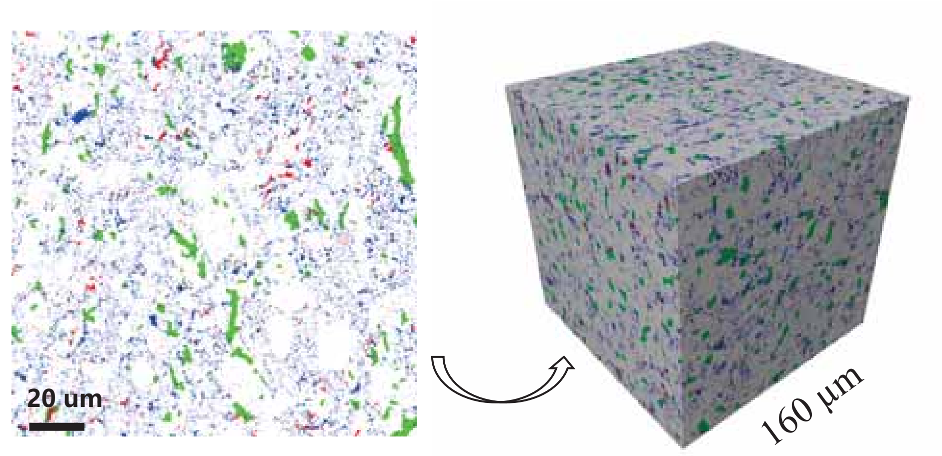
Examples of multiscale/across-scale pore structures

Gas diffusion layers + Micro porous layer



GDL MPL

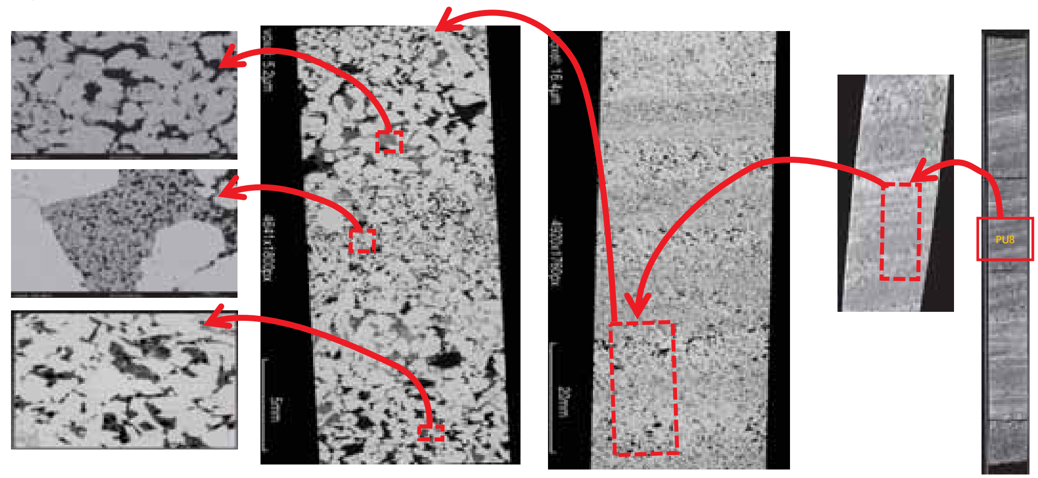
Deep-learning construction of digital rocks of shale matrix



To sum up:

- ❑ Multiscale pore structures are ubiquitous
- ❑ Associated with different minerals or materials, which may have complex wettability
- ❑ Necessitate the hybrid models for flow and transport

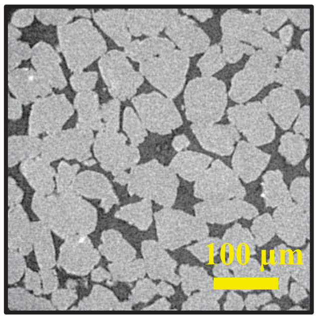
Sandstones

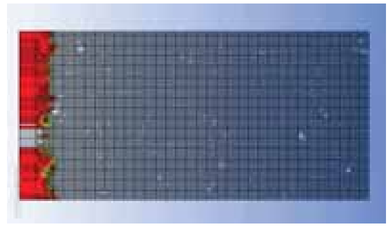


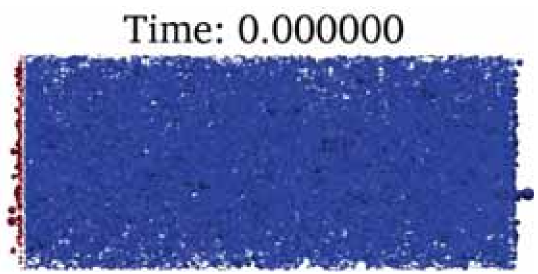
Zoom in ←

Digital Rock Physics: the image-based modeling

Nubian sandstone







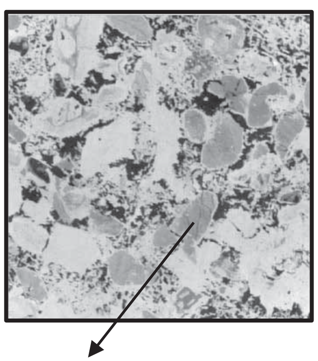
100×100×200 image, DNS of spontaneous imbibition

(*Qin et al., AWR, 2019, 2021, 2025*)

900×900×2000 image

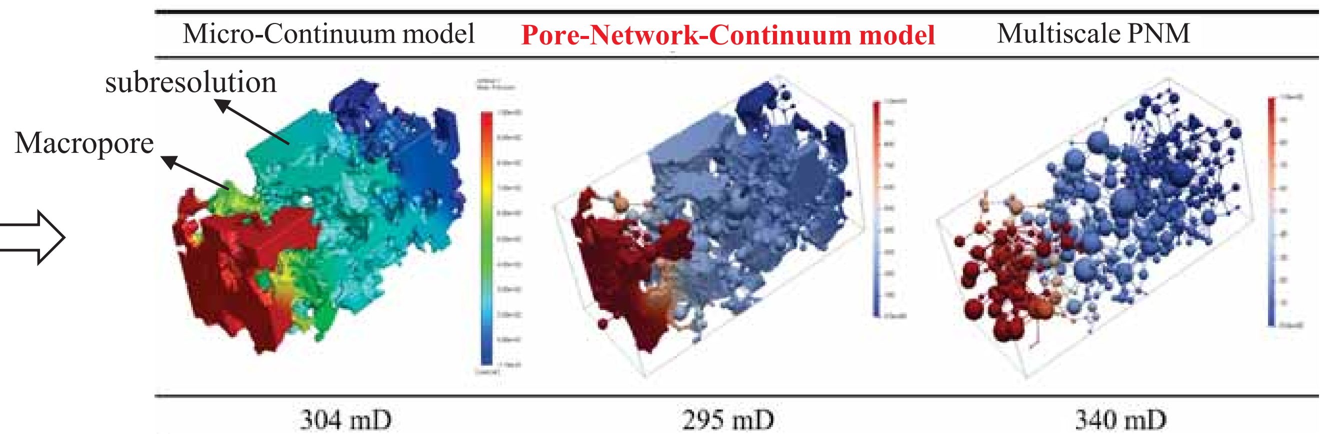
DPNM of spontaneous imbibition

Estaillades



Microporosity

https://www.digitalrocksportal.org



(Zhang, Guo, Qin, and Xiong, AWR, 2024) *(Zhao et al., TiPM, 2025)*

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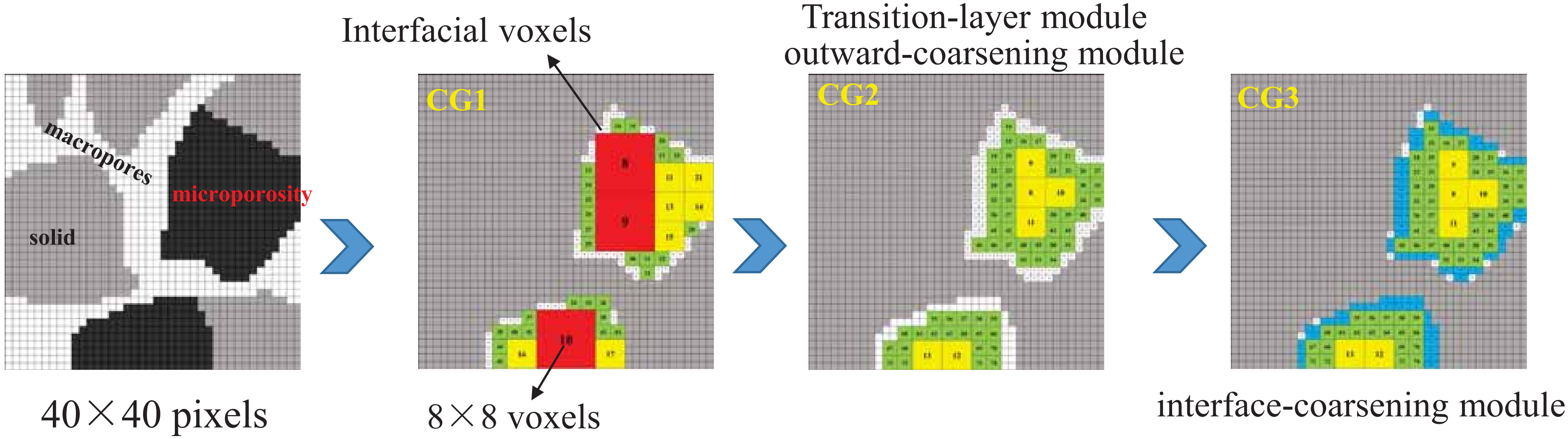
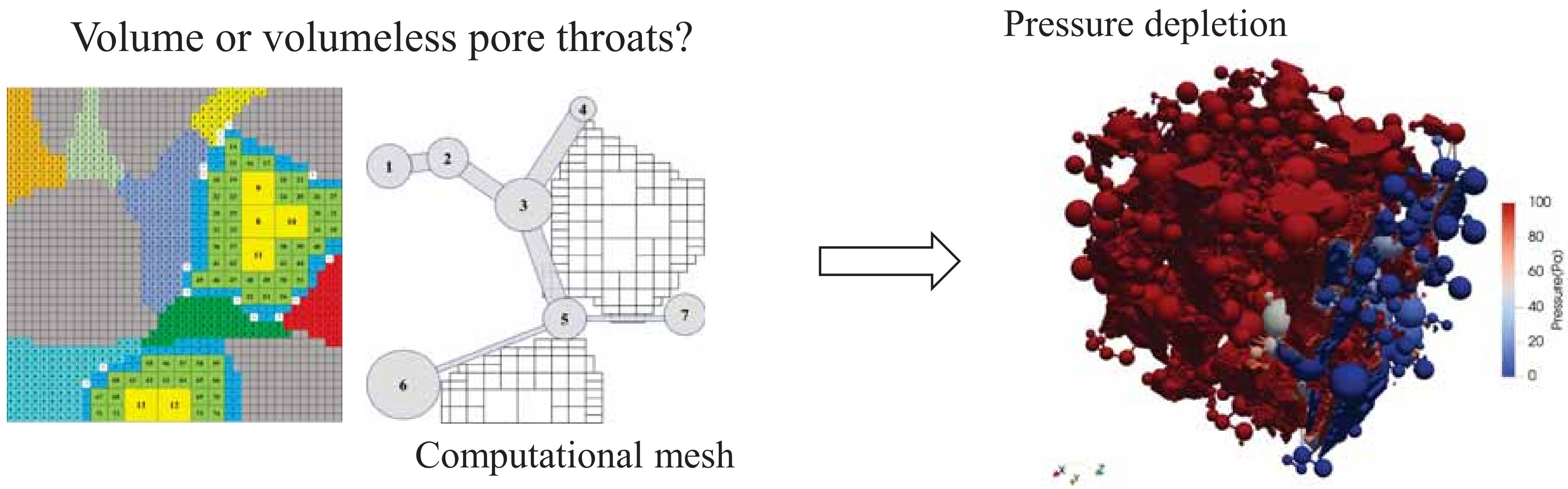
The pore-network-continuum model: framework



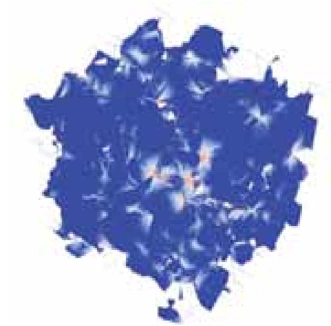


Shi et al., Modeling of flow and transport in multiscale digital rocks aided by grid coarsening of microporous domains, Journal of Hydrology 633 (2024) 131003.

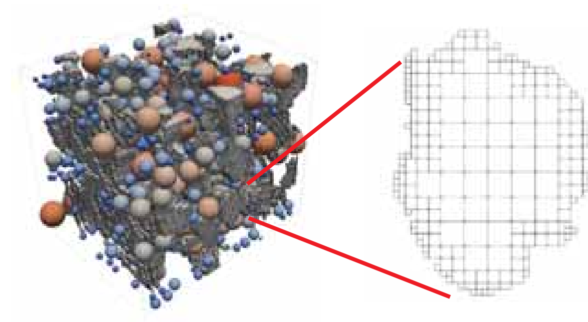
The pore-network-continuum model: coarsening effect

200^3 Berea sandstone

Microporosity filling



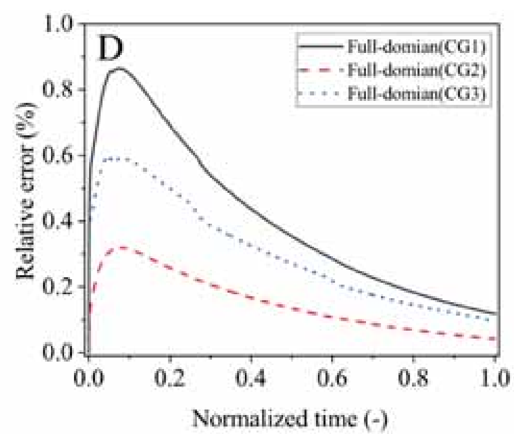
macropores: 539，
microporosity: 1922662



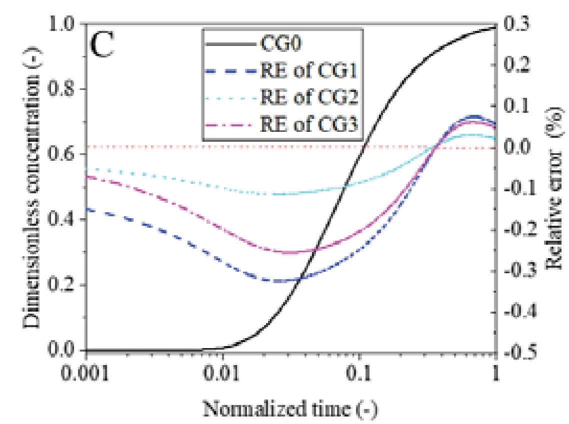
macropores: 539，
microporosity: 273176

Table 1
The details of CG0, CG1, CG2, and CG3 microporosity grids.

Grid type	CG0	CG1	CG2	CG3
macropores	468			
8 × 8 × 8	–	1003	40	98
4 × 4 × 4	–	9520	8350	10,377
2 × 2 × 2	–	60,341	93,009	111,405
2 × 2 × 1	–	–	–	24,945
2 × 1 × 2	–	–	–	10,964
1 × 2 × 2	–	–	–	6242
1 × 1 × 1	1,901,511	295,967	602,559	127,363
In total	1,901,979	367,299	704,426	291,862
Reduction of grids	0 %	80.7 %	63 %	84.7 %



Gas production curves

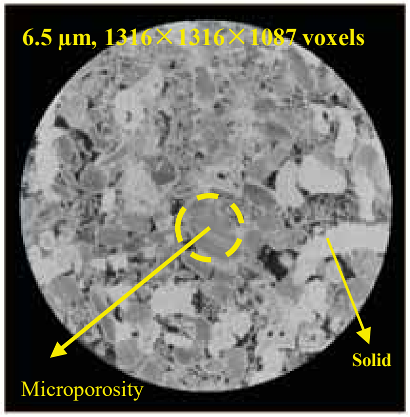


Breakthrough curves

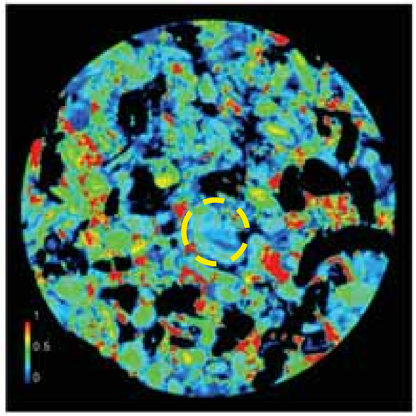
Shi et al., Modeling of flow and transport in multiscale digital rocks aided by grid coarsening of microporous domains, Journal of Hydrology 633 (2024) 131003.

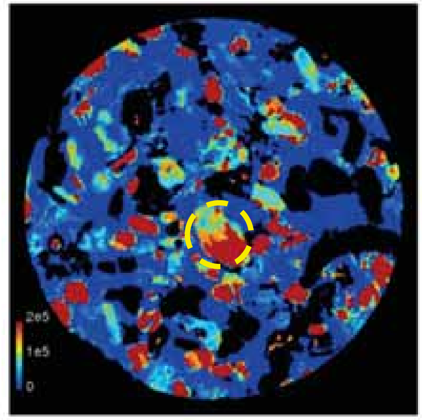
Absolute permeability of Estaillades carbonate rock

(Wang et al., WRR, 2022) https://www.digitalrocksportal.org

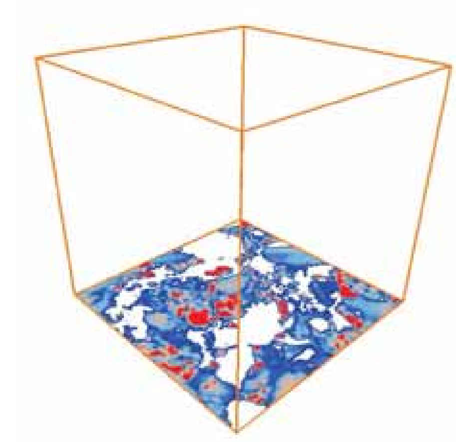


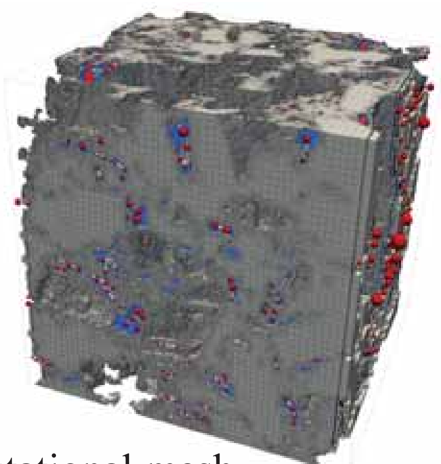
CT grey-scale map

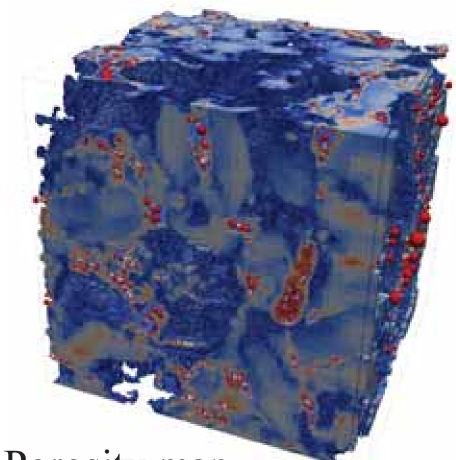

Porosity map

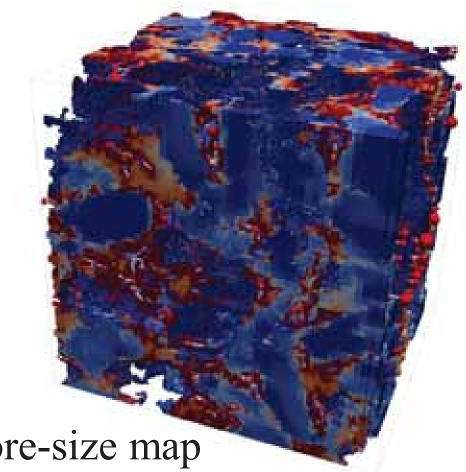

Entry pressure map

400^3 test core：



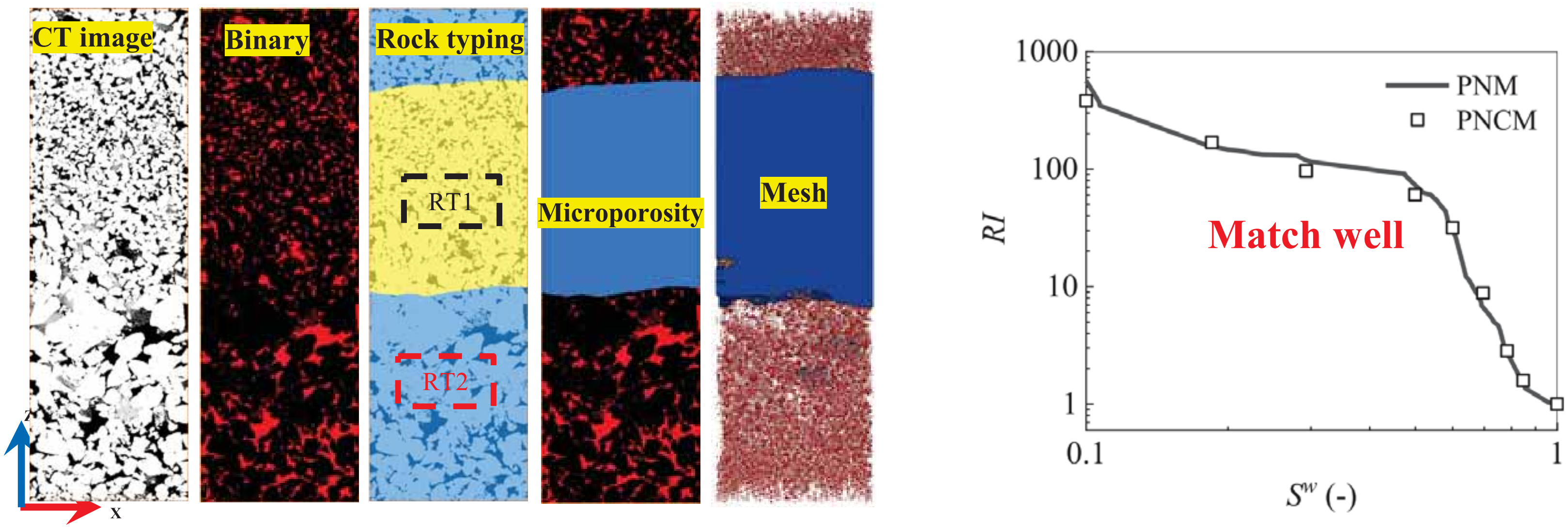

Computational mesh


Porosity map

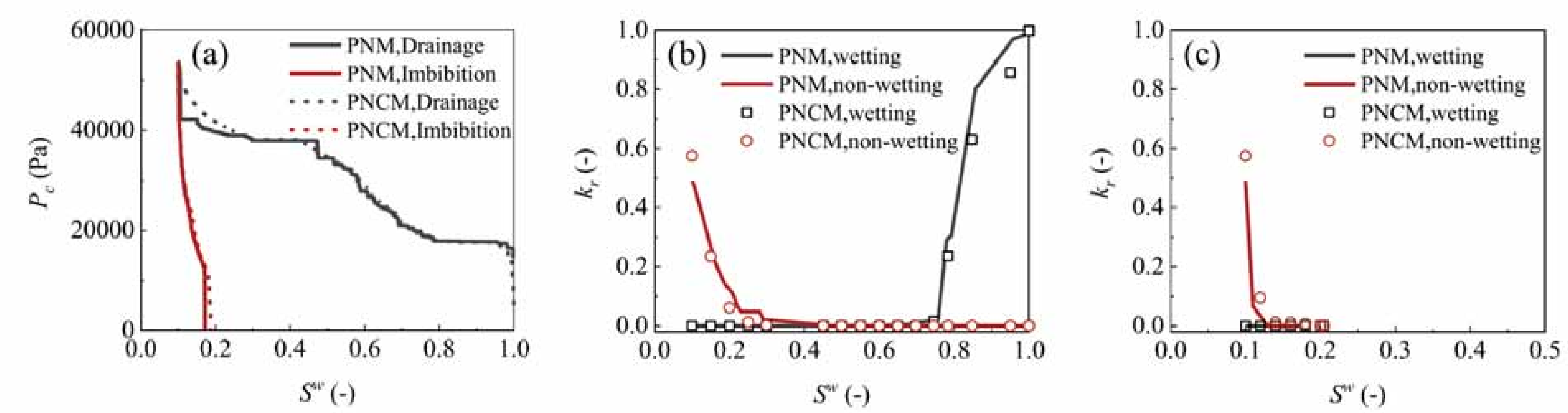

Pore-size map

- ❑ Absolute permeability: **160 mD** (Exp. 95~283 mD)

Quasi-static modeling: verification against the full PNM

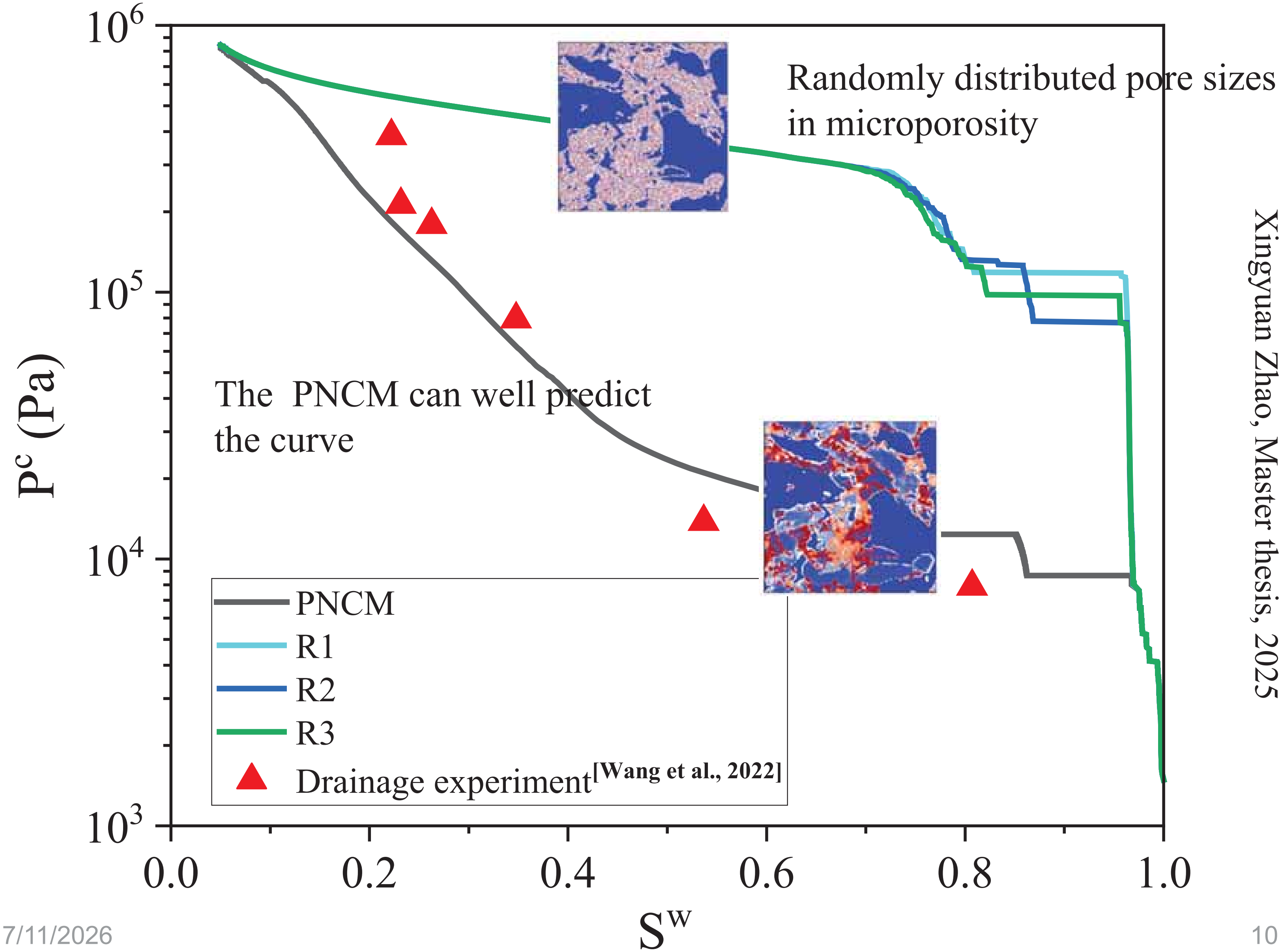


Capillary pressure and relative permeability



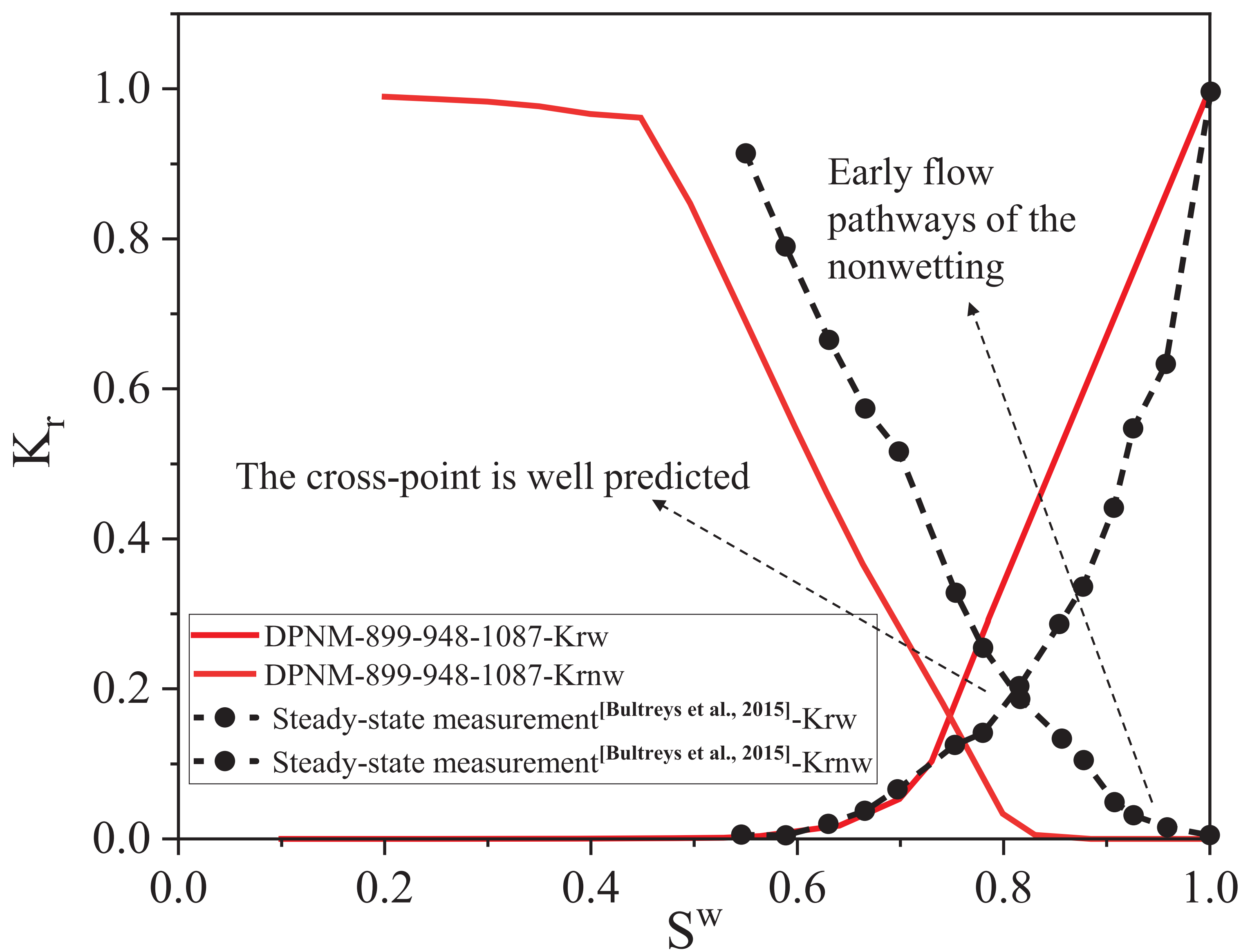
Shi et al., The pore-network-continuum modeling of two-phase flow properties for multiscale digital rocks, AWR, 206, 105138, 2025

Quasi-static modeling: validated against measurements



Xingyuan Zhao, Master thesis, 2025

Quasi-static modeling: validated against measurements



Xingyuan Zhao, Master thesis, 2025

Outline

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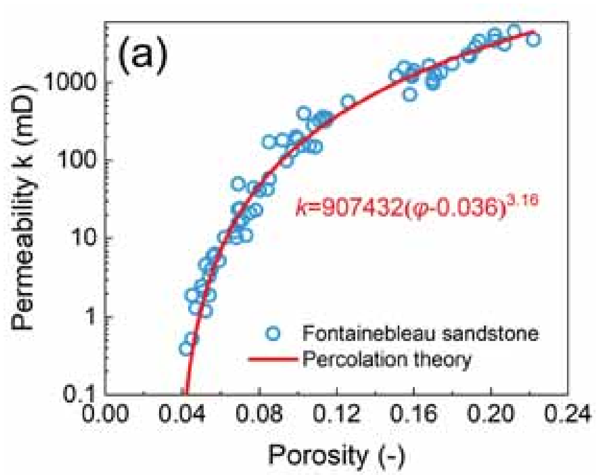
4. **Summary and outlook**

Motivation

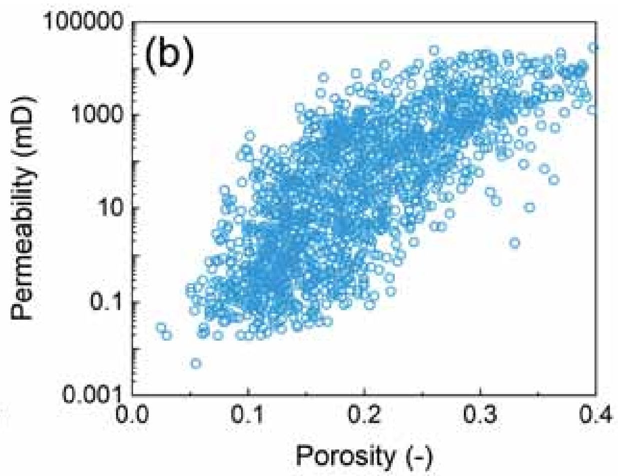
Dewhurst et al., 1998; Mesri and Olson, 1971; Nagaraj et al., 1996; Yang and Aplin, 2007; 2010

André Revil et al., 2014

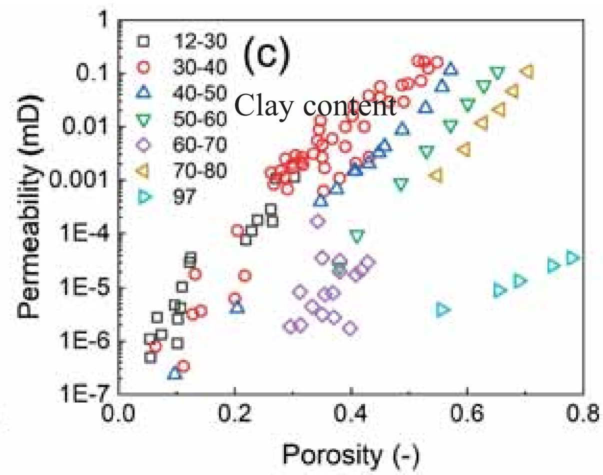


69 clay-free sandstones

Walderhaug et al., 2012



1718 clay-bearing sandstones

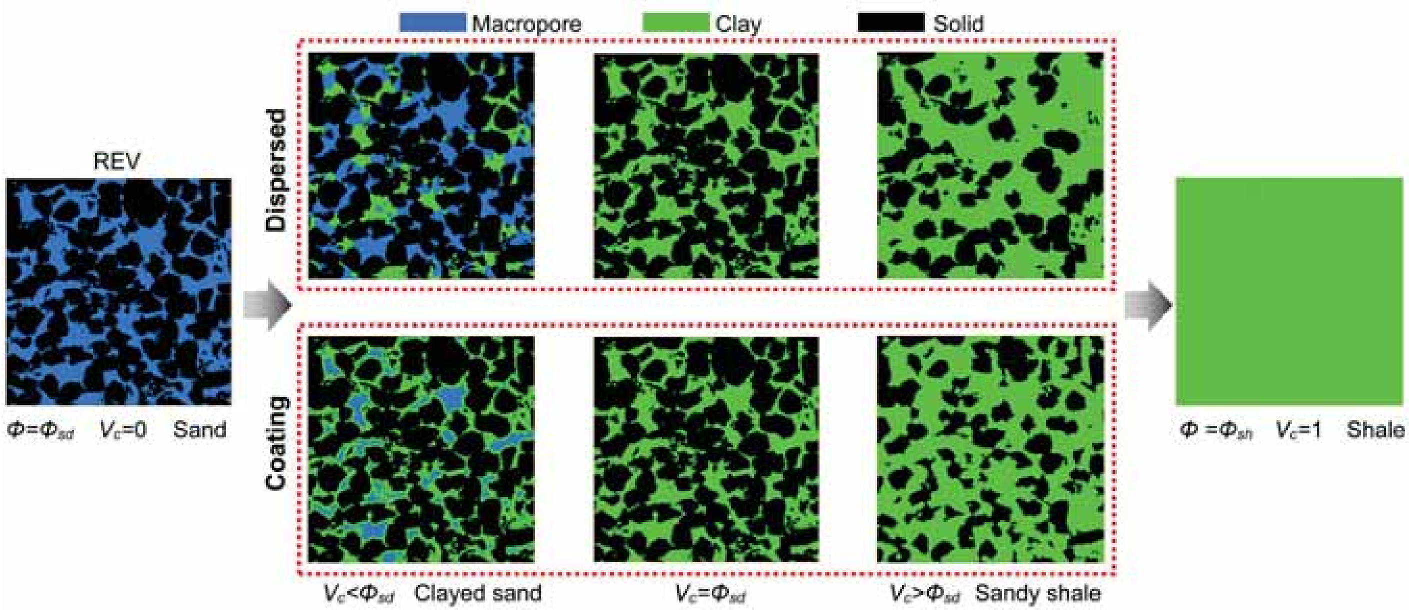


115 clay-rich mudstones

- ❑ Porosity (total porosity) itself **cannot** determine the permeability.
- ❑ The development of **an empirical equation** is of interest.
- ❑ The **correlation** between permeability and formation factor is of interest.

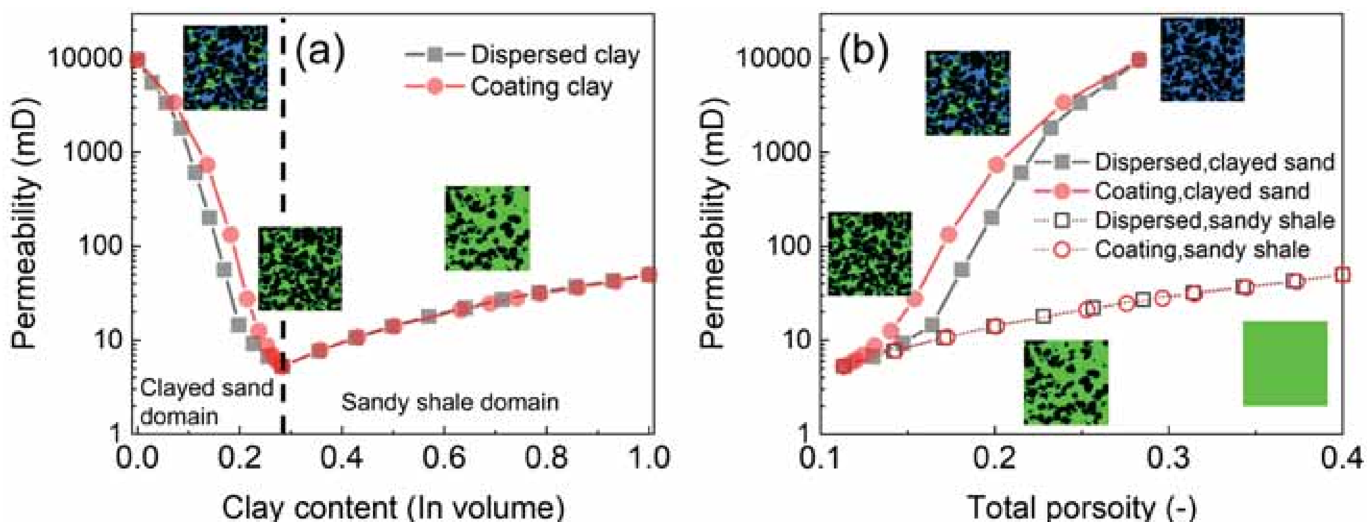
Construction of digital rocks + the pore-network-continuum modeling

Digital rocks of clay-bearing sandstones



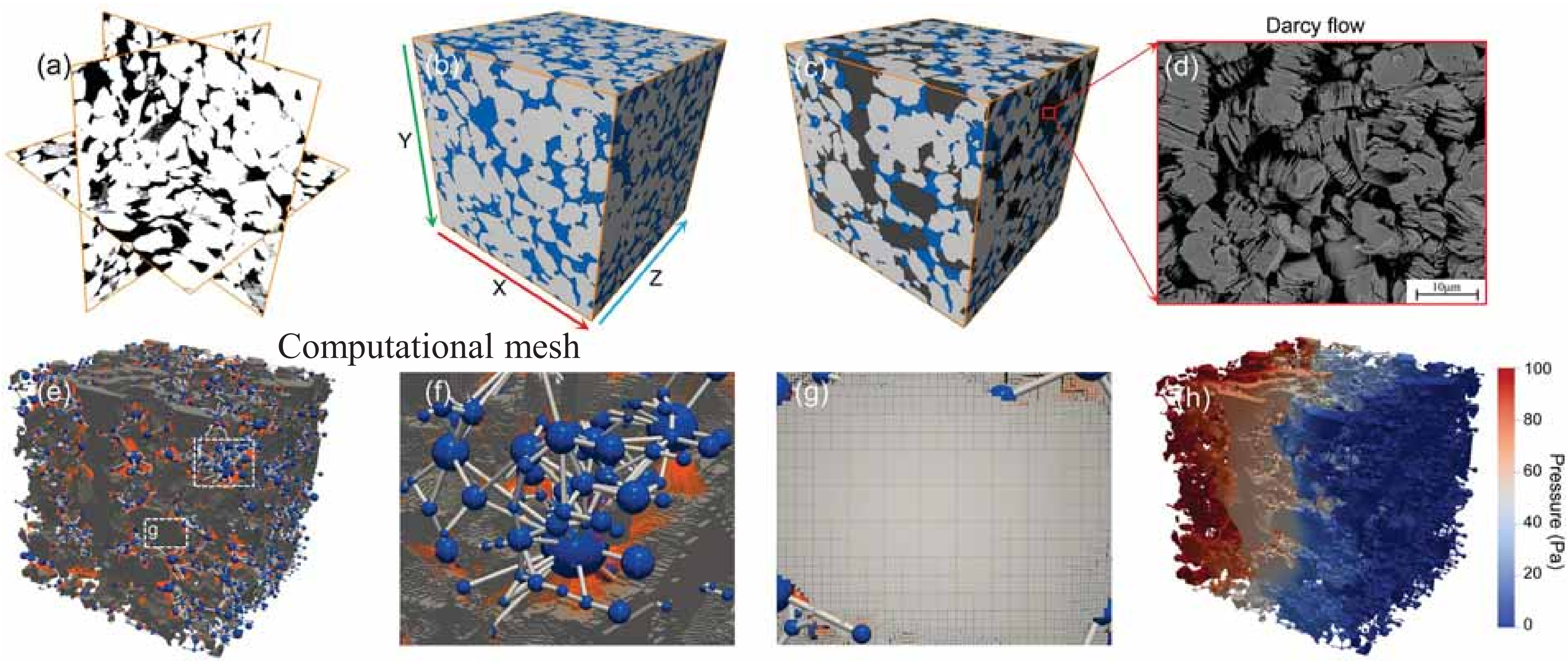
Two approaches to numerically generate digital rocks

Both can capture the change of permeability as clay content and total porosity.



The workflow

Numerically generated



Computational mesh

PNCM modeling

A dataset of **92 digital rocks** is generated, which covers clay contents ranging from **10% to 70%** and total porosities from **12% to 56.3% .**

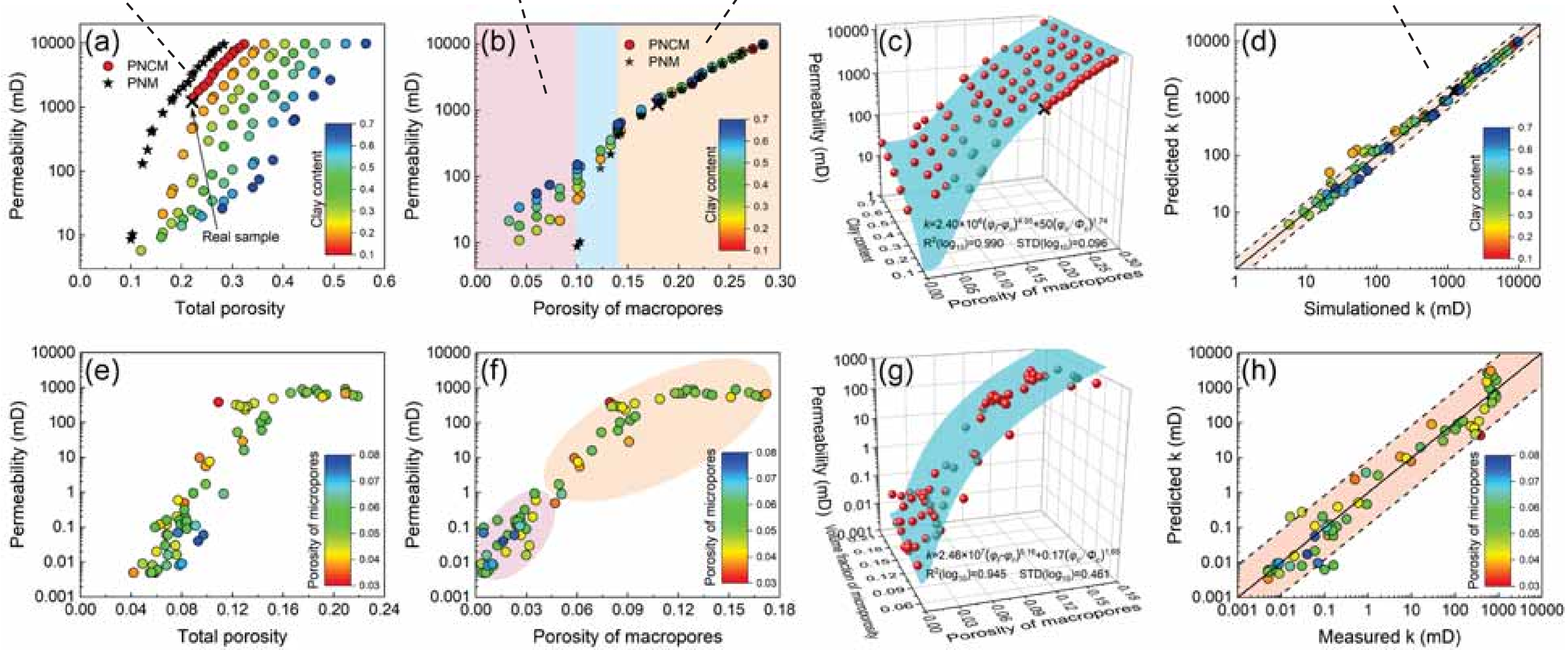
An empirical model

Connected macropores dominate flow capacity

Neglect clays

Clay content and its distribution determine permeability

95% confidence interval narrowly bounded within a factor of 1.58



72 limestone samples

$$k = C_k(\varphi_t - \varphi_c)^{\alpha} + k_c\left(\frac{\varphi_c}{\phi_c}\right)^{\beta}$$

① k [mD]=$2.37\times10^{6}\,(\varphi_t-\varphi_c)^{4.34}+49.76\,(\varphi_c/0.4)^{1.81}$

② k [mD]=$2.4\times10^{6}\,(\varphi_t-\varphi_c)^{4.35}+50\,(\varphi_c/0.4)^{1.74}$

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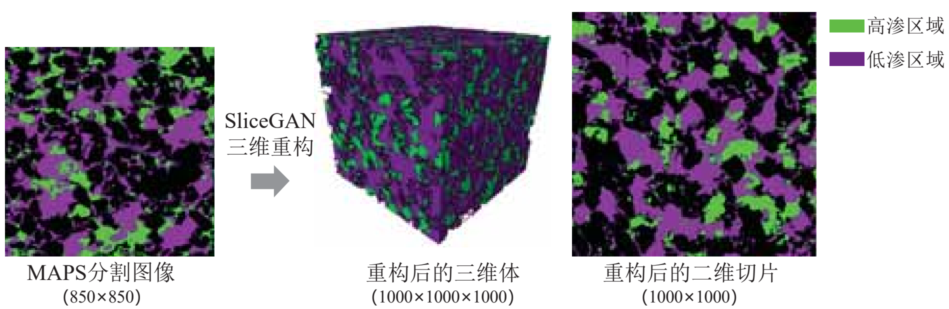
Summary and outlook

- **Multiscale/across-scale pore structures** are ubiquitous in unconventional formations and industrial porous materials.
- We present the **pore-network-continuum hybrid modeling**, which can balance efficiency and accuracy, and validated against experimental data.
- We develop **an empirical model** for permeability of clay-bearing sandstones.

- Develop dynamic PNCM
- Extend empirical equations for two-phase flow parameters
- Develop AI-based construction of multiscale digital rocks
- Applications in industrial porous materials



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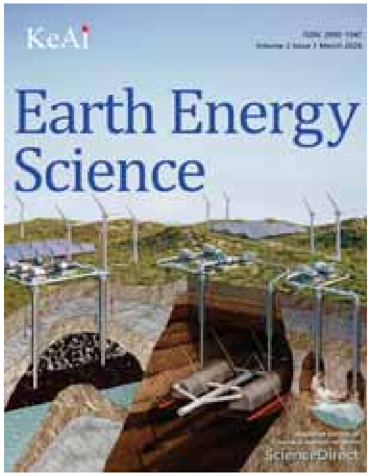
Earth Energy Science



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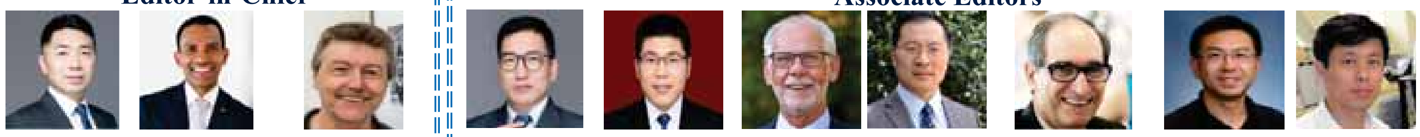

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Journal progress (2023.12-2026.3)

- ✓ It has been included in Scopus, Ei, DOAJ, CAS, INSPEC and OARL databases, and EI collections are under review.
- ✓ The editorial board and young editorial team composed of renowned scholars from both domestic and international backgrounds have been established.
- ✓ 6 issues (39 articles) have been published, and the journal is published quarterly.
- ✓ The first International Conference on earth energy science was successfully held in 2023, and the second conference was successfully held in November 2025.
- ✓ It was selected as the high starting point new journal of the excellent action plan of Chinese Sci tech journals in 2024.

Thank you for your attention!