InterPore 2022

CHINA UNIVERSITY OF GEOSCIENCES

Multiscale pore structure evolution of shale induced by dilute acid

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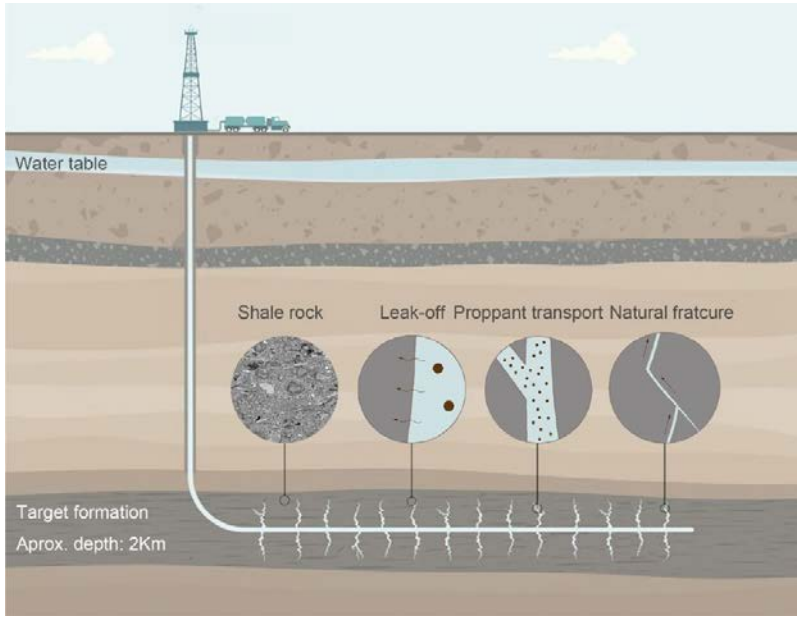
Outline

1. Background
2. Materials and experiments
3. Nanoscale pore structure evolution
4. Microscale pore structure evolution
5. Summary

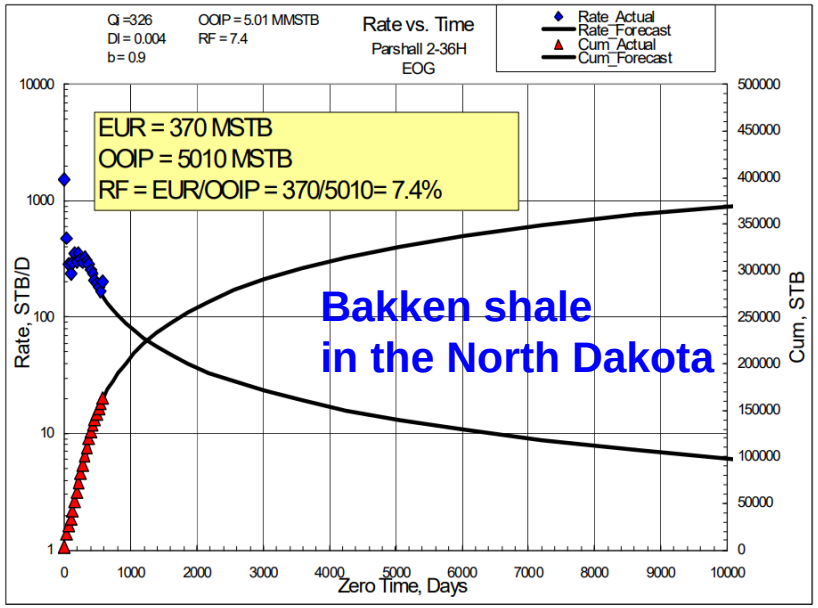
Background

- **Hydraulic fracturing to generate complex fracture networks is the most effective stimulation method to develop unconventional reservoirs, such as shale oil and gas.**
- **The recovery of shale oil and gas is still low, and the production of fractured wells usually suffer a sharp decline in the first few years.**

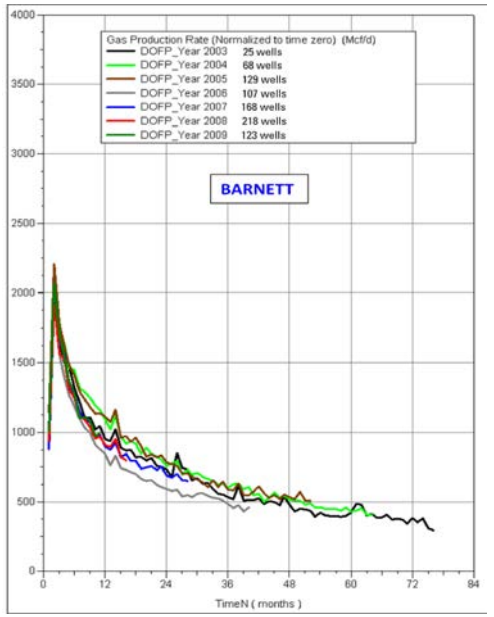
limited stimulated reservoir volume (SRV)



(Chen et al., 2021)



(Clark, 2009)



(Baihly et al., 2010)

Background

Methods of EOR in shale reservoirs:

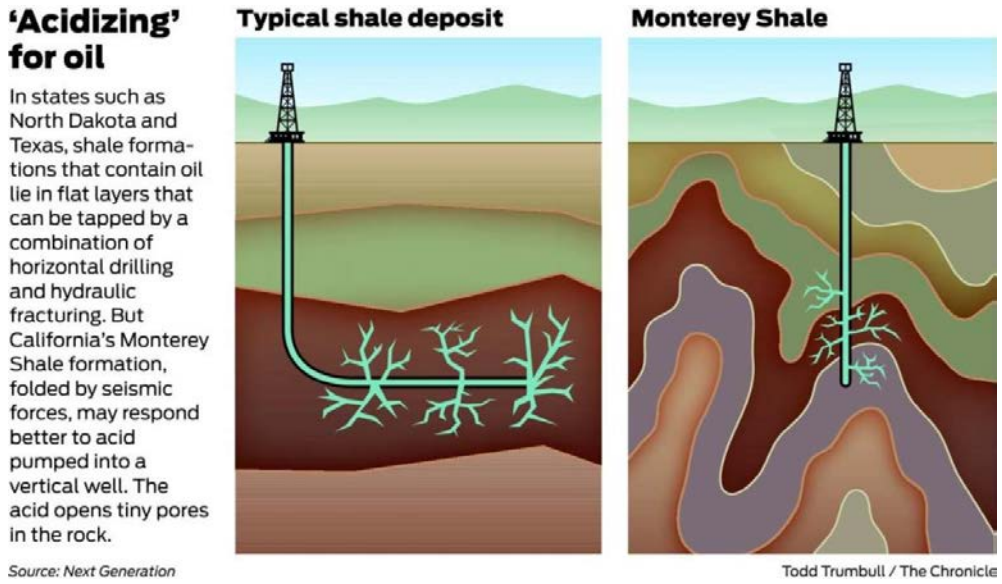
- Surfactant injection
- Gas flooding
- Acid treatment
  - **Matrix acidizing**
    (Injection pressure below breakdown pressure)
  - **Acid fracturing**
    (Injection pressure exceeding breakdown pressure)

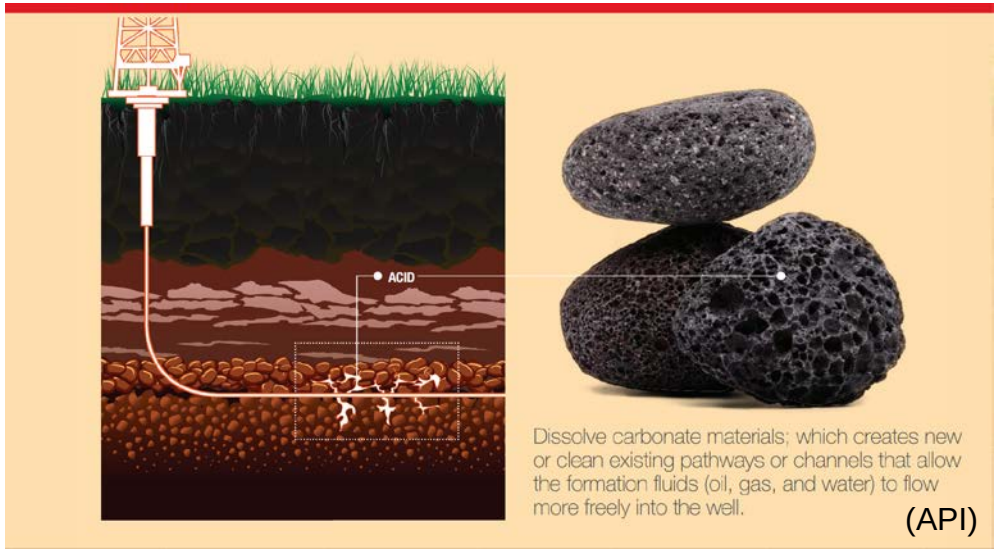
Calcite: $CaCO_3 + 2H^+ = Ca^{2+} + H_2O + CO_2 \uparrow$

Dolomite: $CaMg(CO_3)_2 + 4H^+ = Ca^{2+} + Mg^{2+} + 2H_2O + 2CO_2 \uparrow$

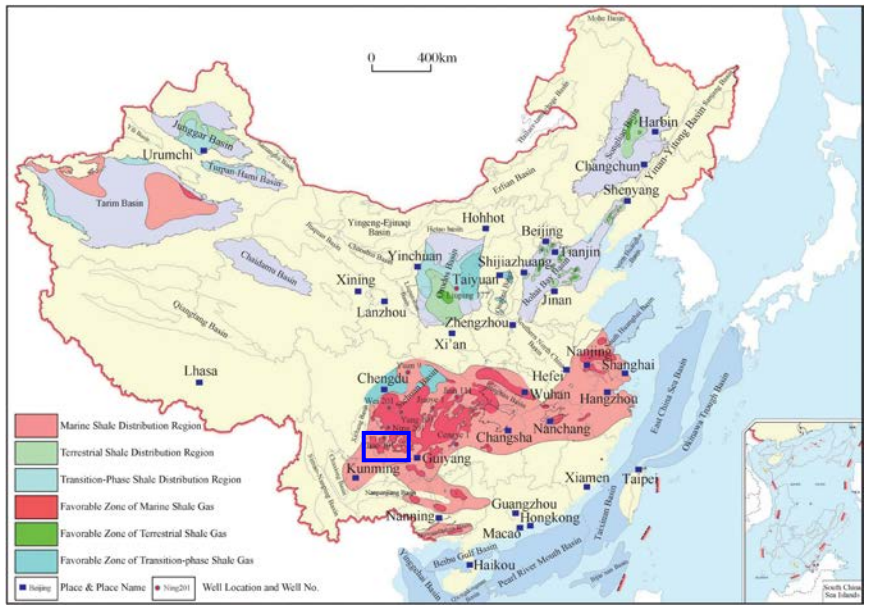
Petrophysical property — Mechanical property

Improve SRV and EOR





Materials and experiments



(Dong et al., 2016)

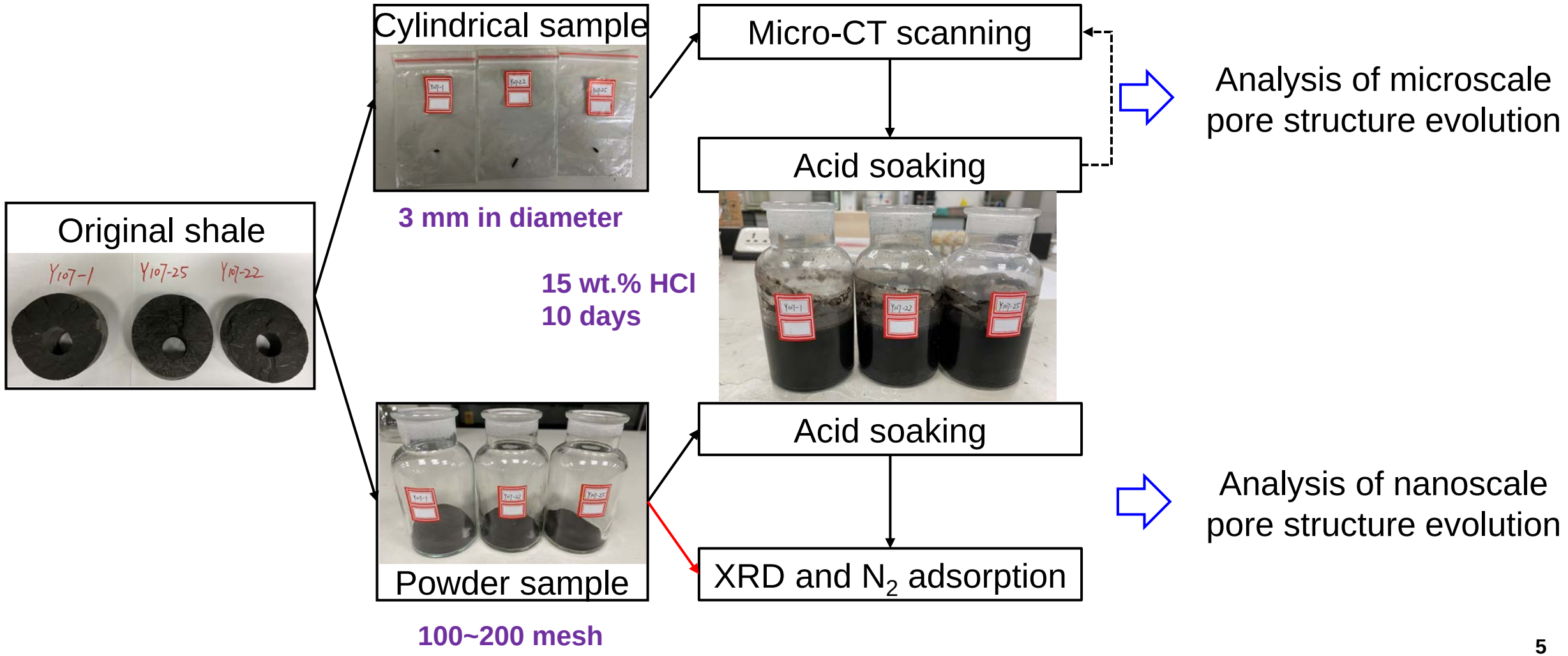
Sample	TOC (%)	Mineral composition (%)						
		Quartz	K-Feldspar	Plagioclase	Calcite	Dolomite	Pyrite	Clay
Y107-1	0.86	34.8	2.2	10.3	12.2	9.8	2.1	28.6
Y107-22	3.26	50.6	1	2.9	12.3	5	4.6	23.6
Y107-25	3.54	38.3	—	2.3	25.1	13.8	4.5	16

Longmaxi black shale from Zhaotong shale gas demonstration area

- **Clay-rich shale: Y107-1, Y107-22**
- **Carbonate-rich shale: Y107-25**

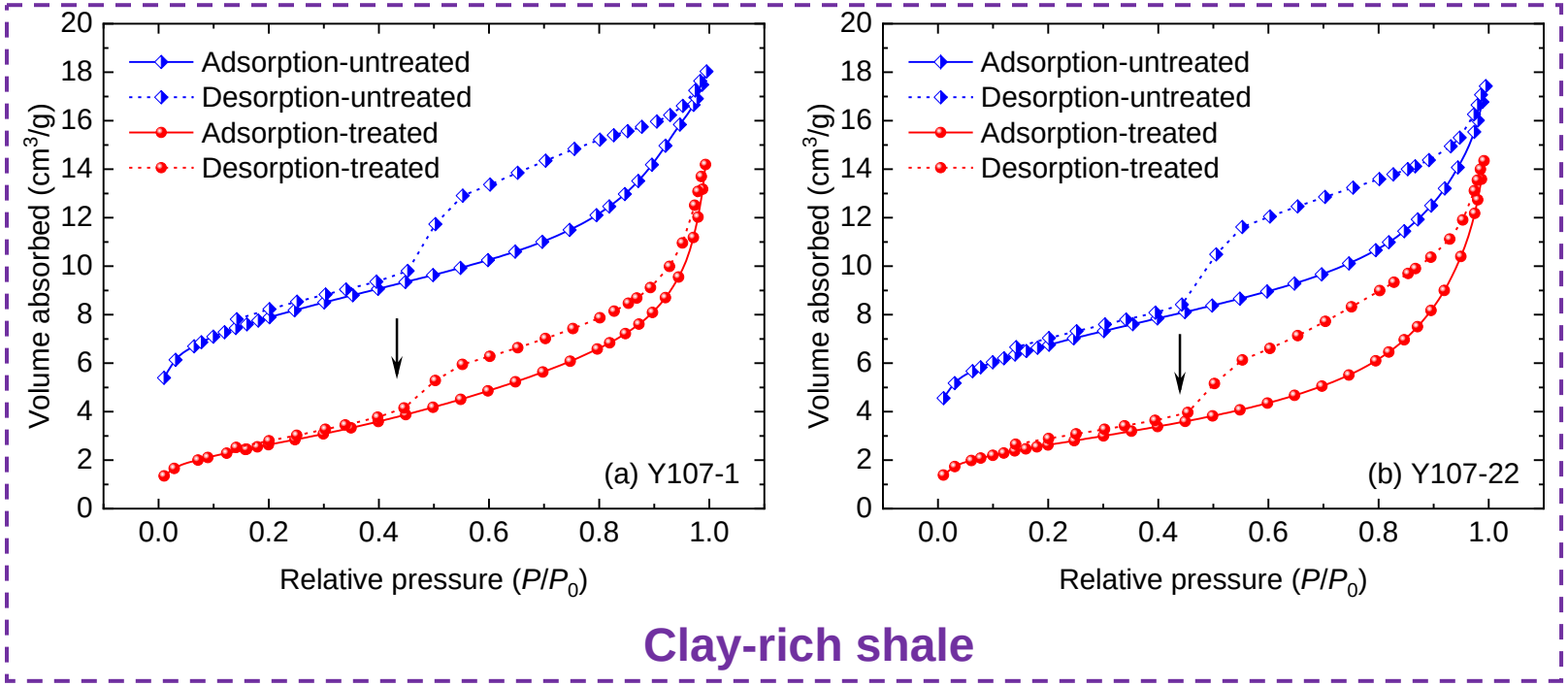
Materials and experiments

Experimental workflow



Nanoscale pore structure evolution

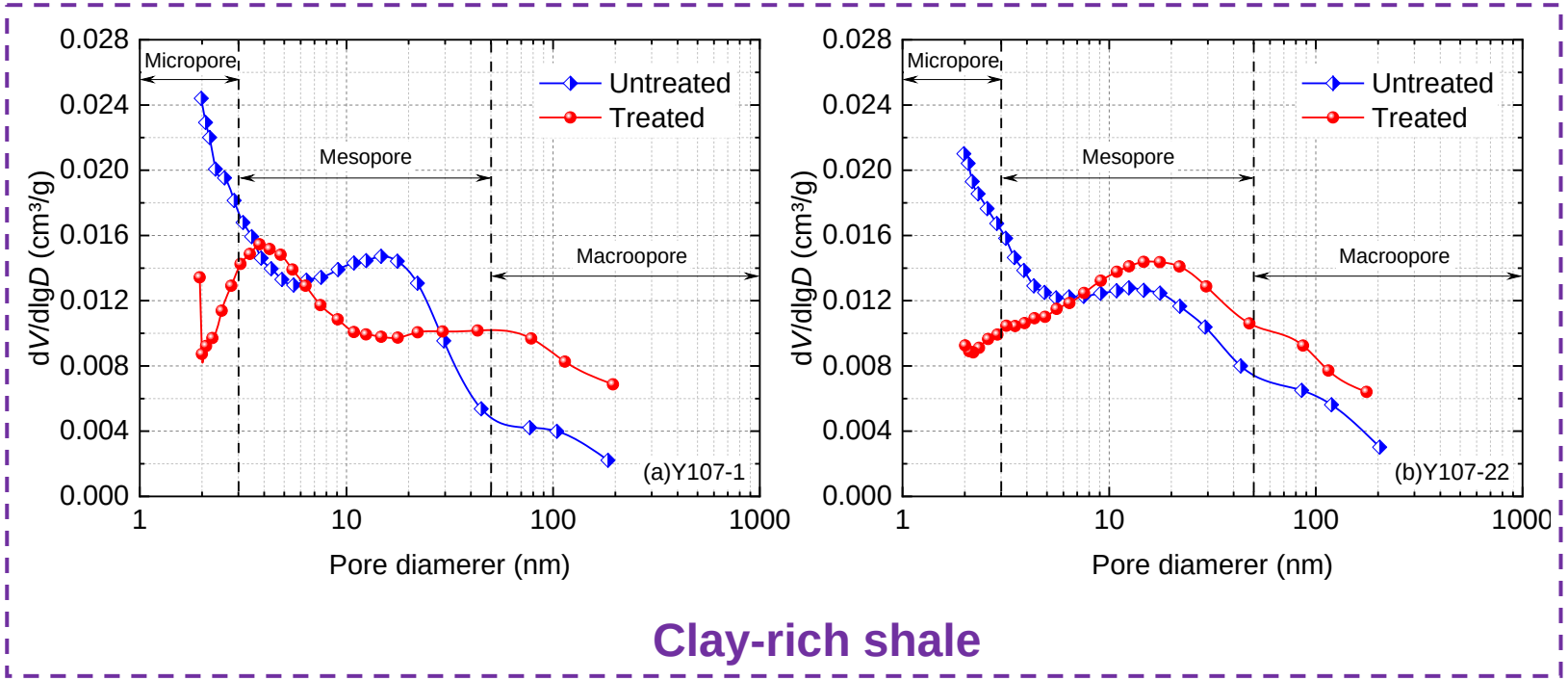
Variations in N_2 adsorption-desorption isotherms



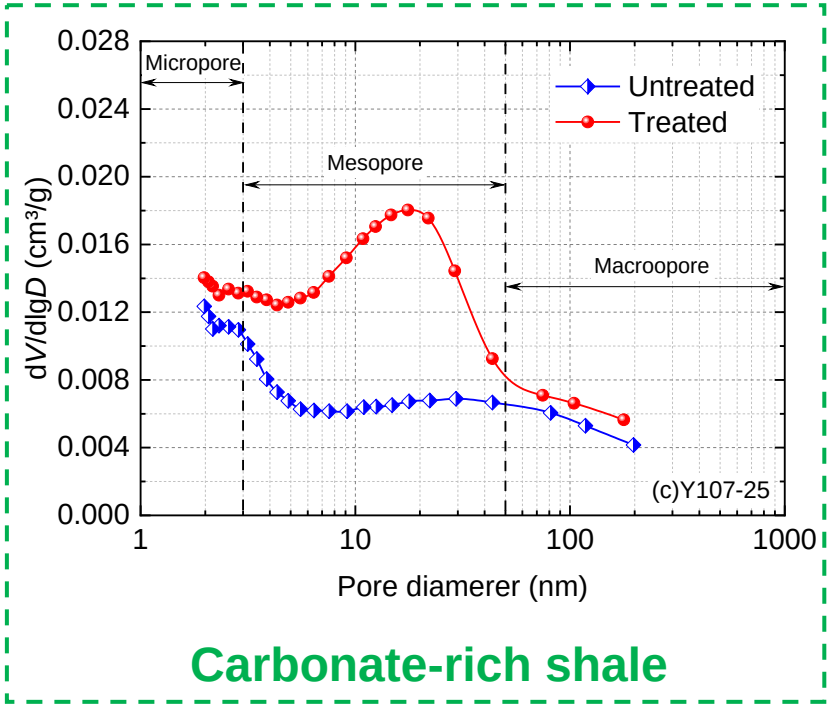
- For clay-rich shale, the shape of isotherms barely changed, while the locations obviously shifted downward.
- For Carbonate-rich shale, the shape of isotherms changed a lot. At relative pressure lower than 0.45, the isotherms almost coincided. When relative pressure exceeded 0.45, much more quantity of N_2 was adsorbed, with a more obvious hysteresis loop.

Nanoscale pore structure evolution

Variations in pore size distribution



Clay-rich shale

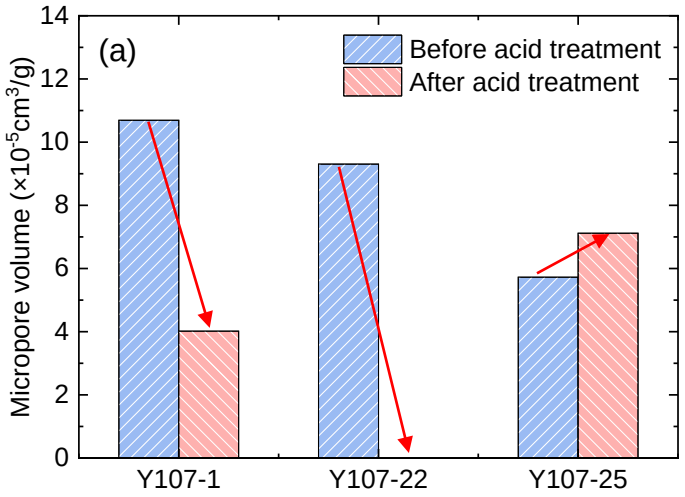


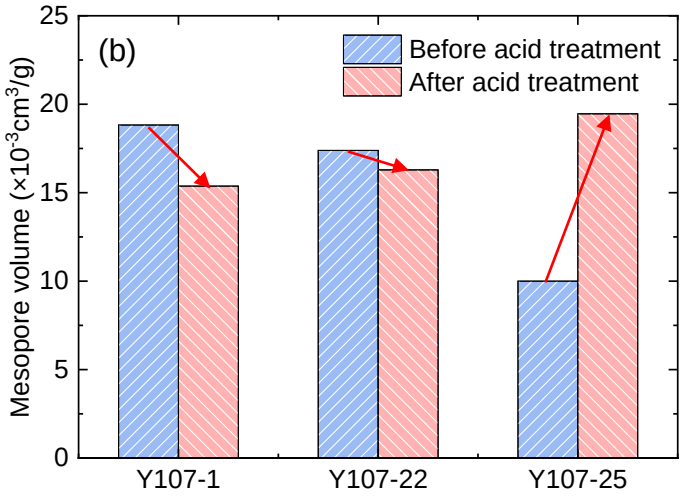
Carbonate-rich shale

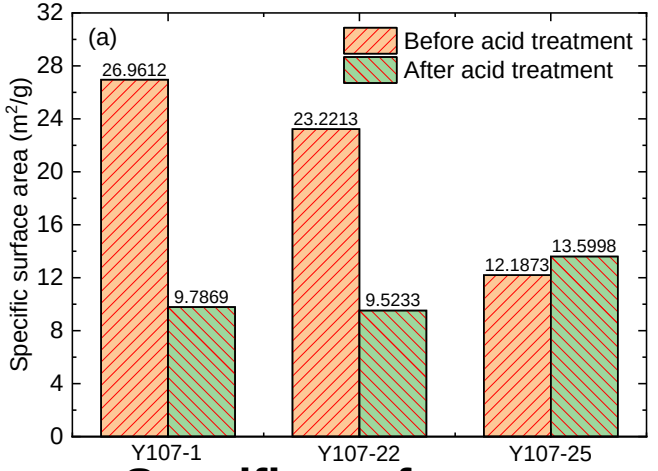
- In clay-rich shale, some micropores and mesopores decreased, while macropores increased.
- In carbonate-rich shale, all the nanopores increased.

Nanoscale pore structure evolution

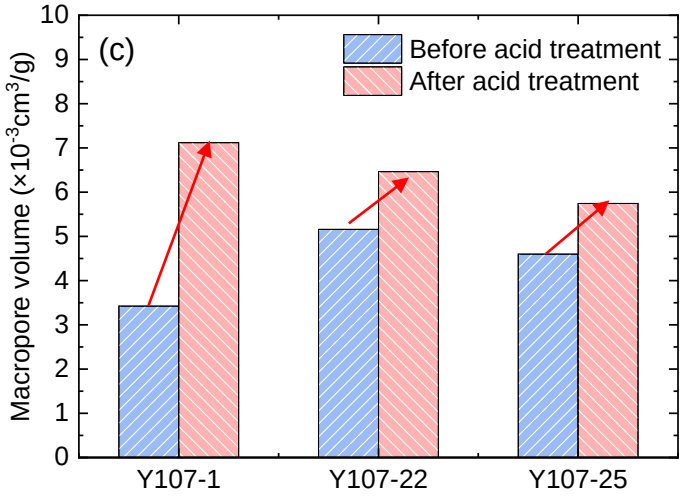
Variations in pore structure

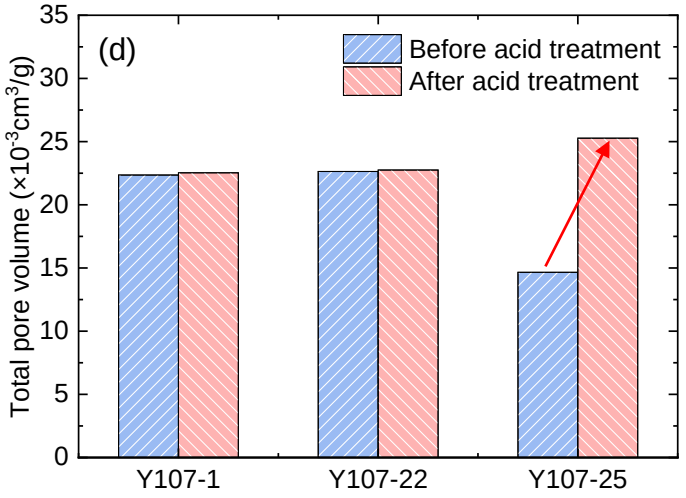




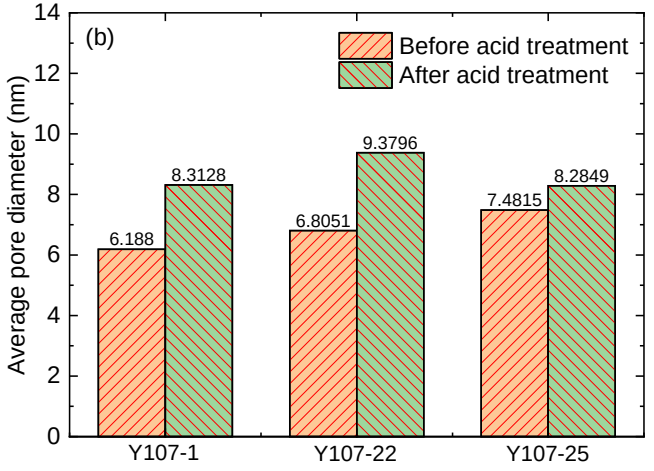


Specific surface area





Pore volume



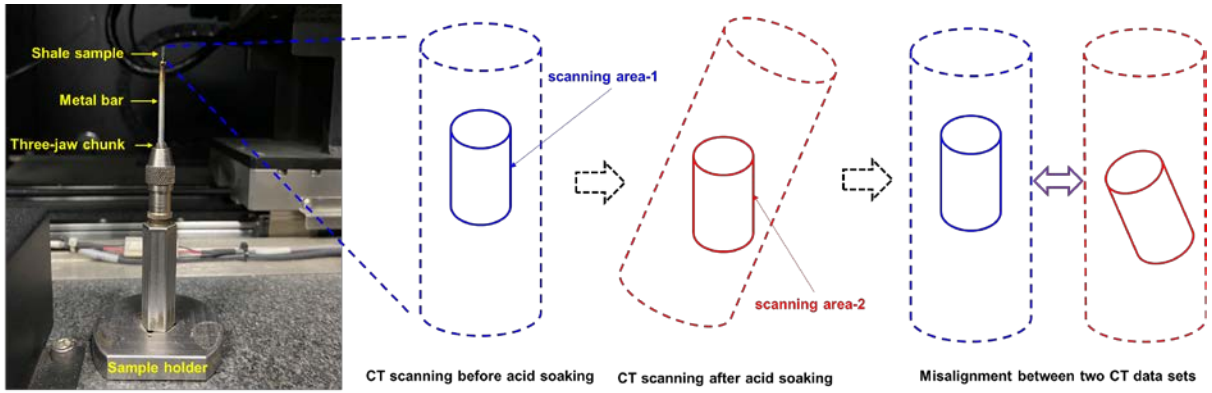
Average pore diameter

Microscale pore structure evolution

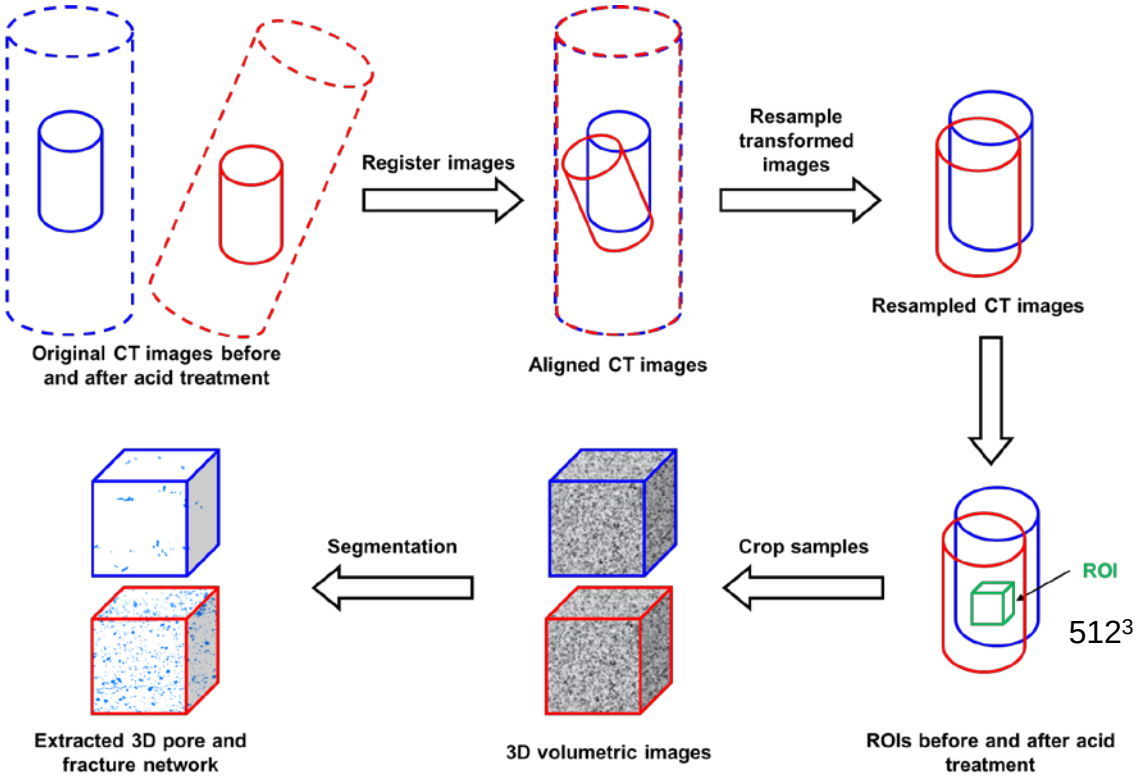
CT scanning and image processing

Zeiss Versa XRM-500 CT Scanner

961 sheets of CT slices with a resolution of 1.78 μm were acquired for each sample



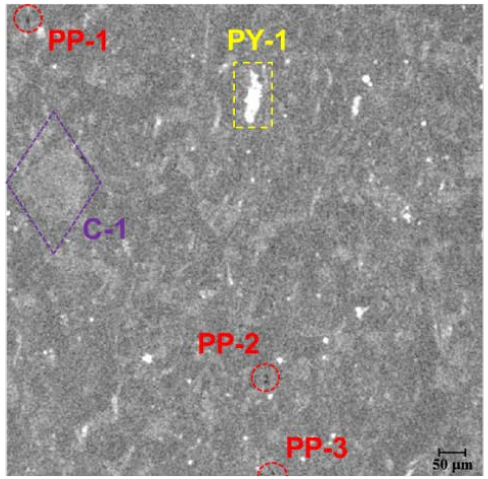
Misalignment of CT images



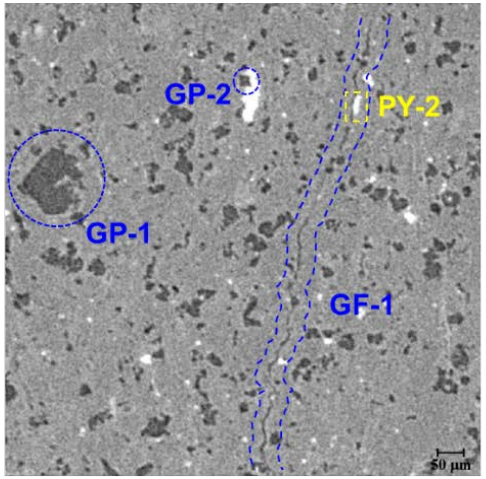
Workflow followed for processing CT images

Microscale pore structure evolution

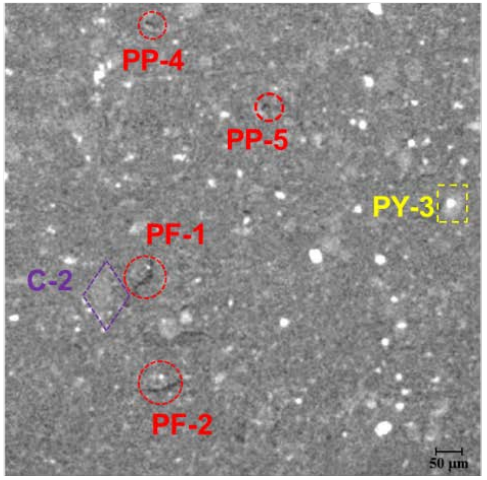
Variation in minerals, pores and fractures from 2D CT images



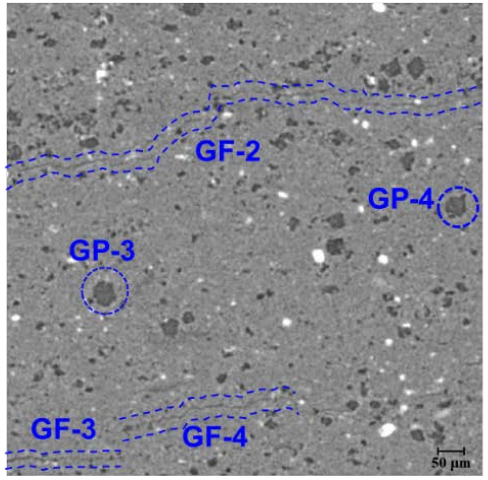
(a) Y107-1 before acid treatment



(b) Y107-1 after acid treatment



(c) Y107-25 before acid treatment



(d) Y107-25 after acid treatment

- **Massive dissolution of Calcite**

  (C-1, GP-1)
- **Partial dissolution of pyrite adjacent to carbonate**

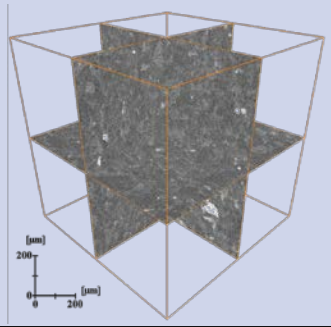
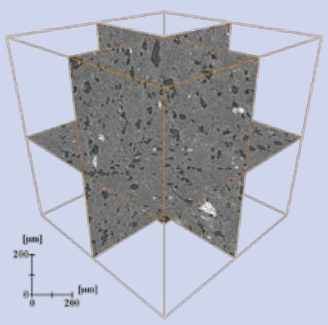
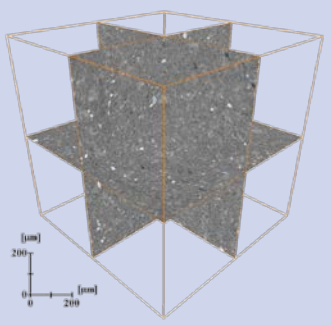
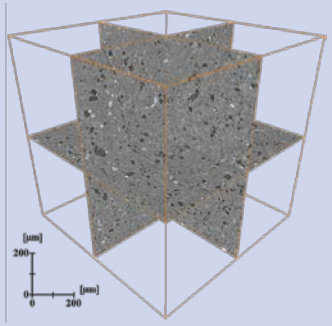
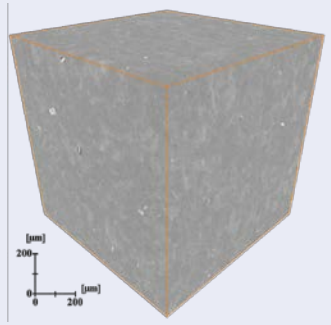
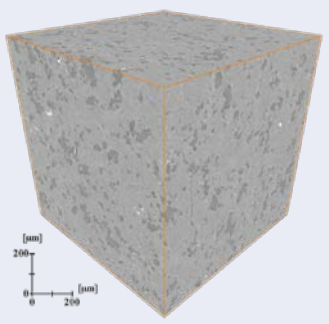
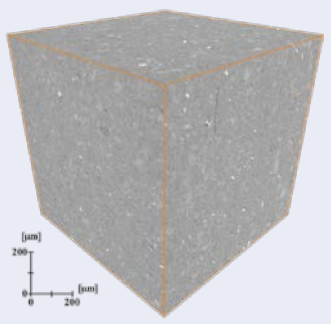
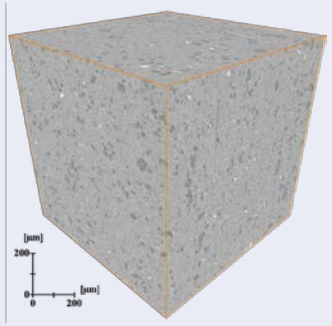
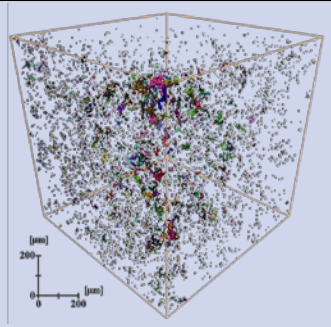
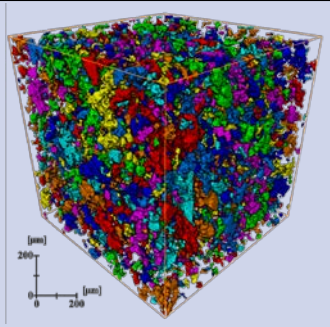
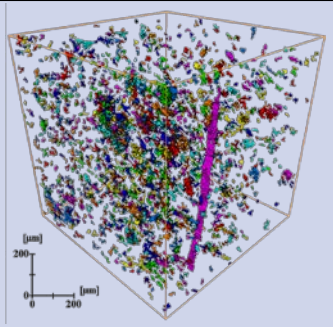
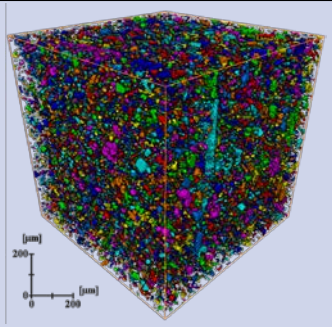
  (PY-1, PY-3)
- **Generation of pores and fractures**

  (GP-1, GP-2, GP-3, GF-1, and GF-2)
- **Shrinkage of pre-existing pores and fractures**

  (PP-2, PF-1 and PF-2)

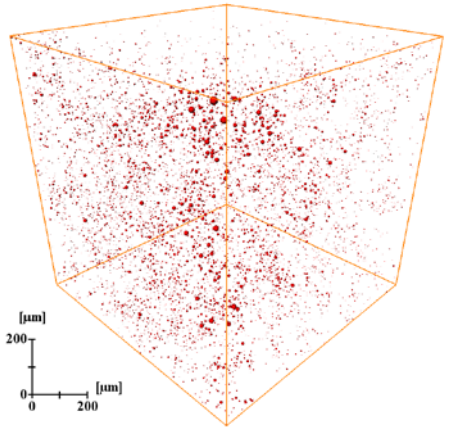
Microscale pore structure evolution

Variation in pore structure from 3D

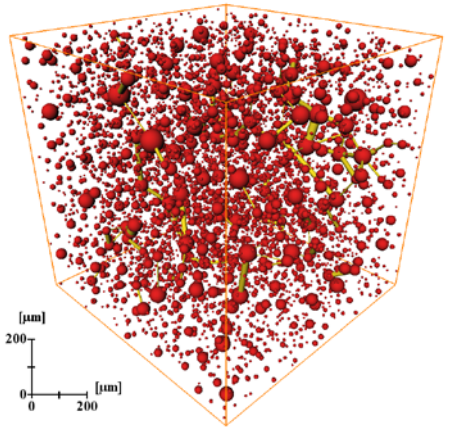
	Untreated Y107-1	Treated Y107-1	Untreated Y107-25	Treated Y107-25
2D slices in x, y, and z directions				
3D grayscale images				
3D color-labeled pores and fractures				

Microscale pore structure evolution

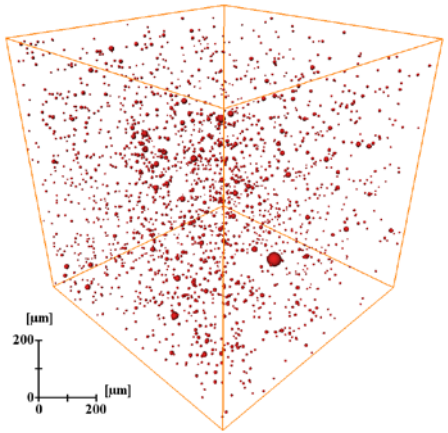
Variation in pore structure from pore network models



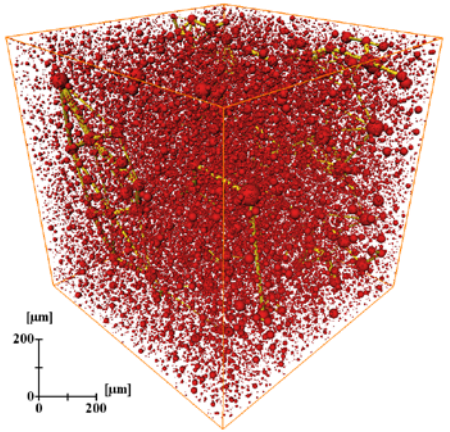
Y107-1 before



Y107-1 after



Y107-25 before

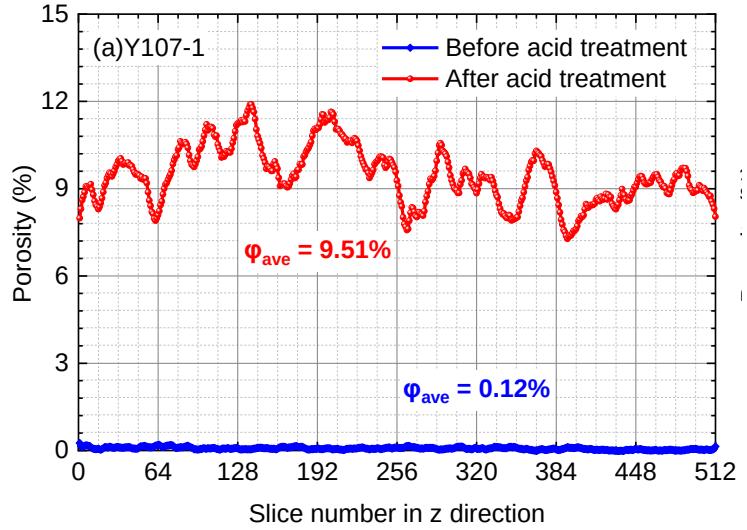


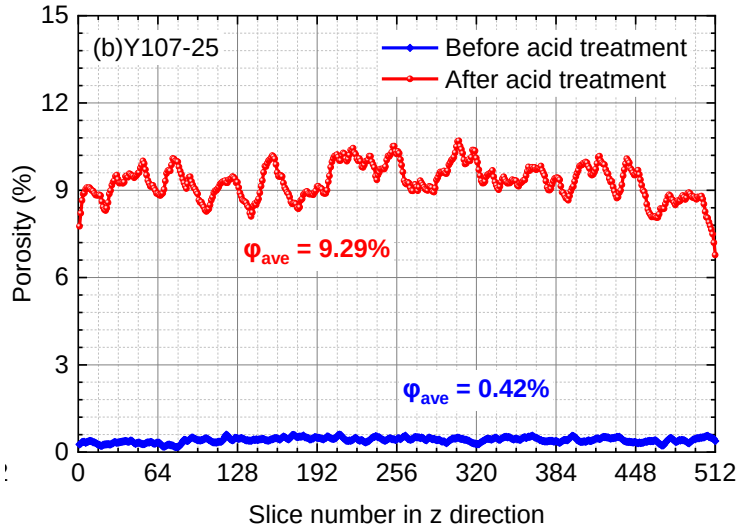
Y107-25 after

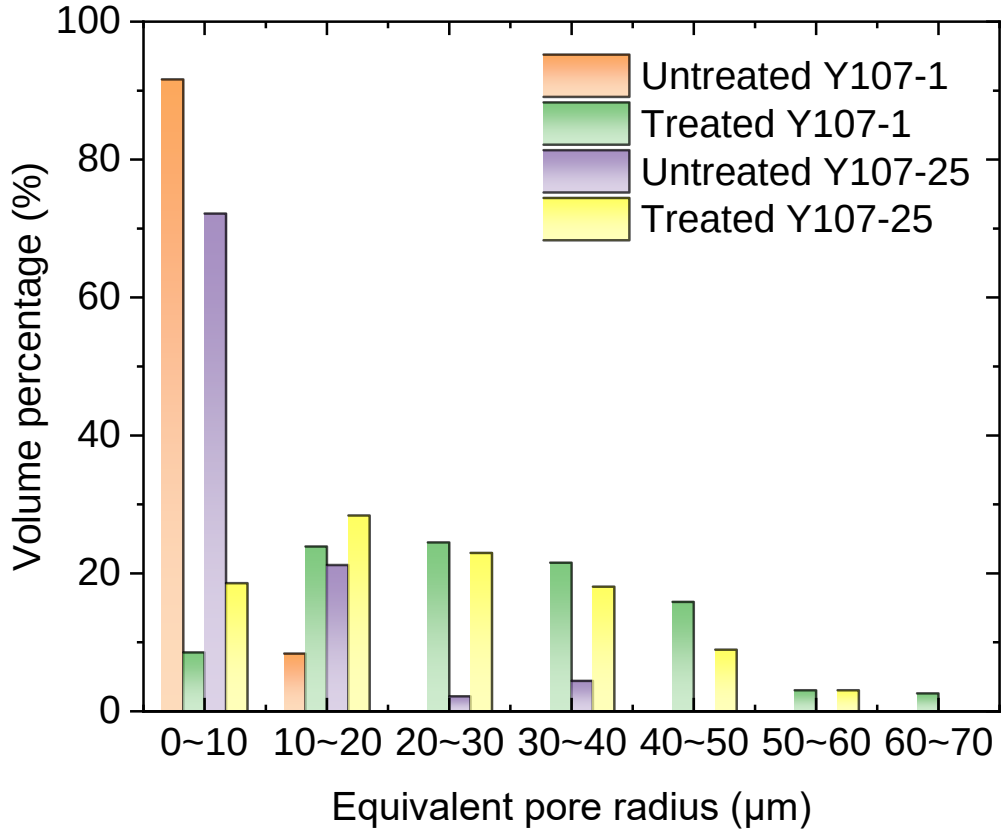
Sample	V_{total} (μm³)	V_{max} (μm³)	V_{ave} (μm³)	S_{max} (μm²)	S_{ave} (μm²)	R_{max} (μm)	R_{ave} (μm)	F_c (%)
Untreated Y107-1	939329.82	13873.46	126.95	7011.41	107.62	14.91	2.48	0
Treated Y107-1	72096260.58	956760.38	13711.74	211412.66	4832.77	61.13	10.79	32.21
Untreated Y107-25	3150698.14	138740.25	1498.90	64222.07	1062.67	32.11	6.53	0
Treated Y107-25	70389090.03	796309.50	7113.60	409407.56	3080.10	57.50	9.13	36.78

Microscale pore structure evolution

Variation in pore structure from pore network models







This significant increase in porosity and pore size could substantially improve permeability

Summary

1. An experimental workflow combining CT and N_2 adsorption is developed to study the multiscale pore structure evolution of shale induced by acid treatment.
2. Clay-rich and carbonate-rich shales show differences in variation of pore structure.
3. Acid treatment results in an increase of about 9% in porosity.
4. Acid treatment is a promising strategy to develop Longmaxi shale reservoirs by improving petrophysical properties and SRV.