

# **PS Pore Structure Classification of Carbonate Rocks Based on Rock Type Analysis and NMR Experiments\***

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## **Abstract**

An integrated petrographical and petrophysical study was carried out on a set of 20 carbonate core samples in Ordovician reservoirs with depth more than 5500 m, covering a wide range of lithologies and textures. In this study, various carbonate rock-types have been characterized, by integrating both sediment-petrological and petrophysical data, including thin sections, porosity, permeability, low-field Nuclear Magnetic Resonance (NMR) and Mercury-injection capillary pressure (MICP). Based on the petrographical and petrophysical analysis, 6 groups of rock types were identified, and each of them characterized by a unique NMR signature: (1) Grainstone, (2) Packstone, (3) Wackstone, (4) Mudstone, (5) limestone with full-filled fractures and (6) limestone with half-filled fractures. NMR T2 distributions were linked to pore body size and T2 logarithmic (T2lm) was calculated. It is apparent that packstone, wackstone and mudstone of the carbonate reservoirs in this study, yield smaller pore body sizes (T2lm < 20 ms), as well as narrower pore throats (average radius < 150 nm) and lower permeability values (typically below 0.1 mD). The grainstone samples yield bimodal T2 distributions, with a first peak related to the cement matrix pores and a second peak related to intraparticle pores. The T2 distributions of limestone with fractures reflecting larger pore sizes (T2lm > 90 ms) and higher permeabilities (up to 10 mD). Additionally, each rock type's NMR characters were tested under different pressure, and their sensitive responses were analyzed, especially for the second peak of grainstone and limestone with fractures. For all samples, permeability was inferred from NMR spectra using Schlumberger Doll Research (SDR) model. The study aims to develop an NMR-based approach to characterize various carbonate rock-types, calibrated by geological and petrophysical analysis. The results allow an in depth understanding of the NMR signal of each carbonate rock-type, and can be used as a guide to interpret NMR logging data.

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# Pore Structure Classification of Carbonate Rocks

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## Abstract

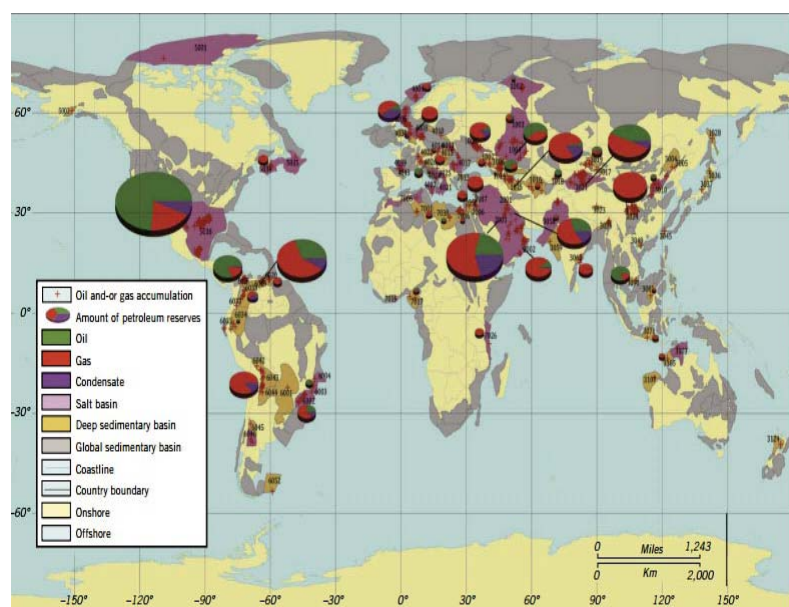
An integrated petrographical and petrophysical study was carried out on a set of 25 carbonate core samples in Ordovician reservoirs with depth more than 5500 m, covering a wide range of lithologies and textures. In this study, various carbonate rock-types have been characterized by integrating both sediment-petrological and petrophysical data, including thin sections, porosity, permeability, Mercury-injection capillary pressure (MICP), and low-field Nuclear Magnetic Resonance (NMR).

Based on the petrographical and petrophysical analysis, 6 groups of rock types were identified, each of them characterized by a unique NMR signature: (1) Mudstone, (2) Wackstone, (3) Packstone, (4) Grainstone, (5) Limestone with half-filled fractures, and (6) Limestone with full-filled fractures. NMR  $T_2$  distributions were linked to pore body size and  $T_2$  logarithmic ( $T_{2lm}$ ) was calculated. It is apparent that packstone, wackstone and mudstone of the carbonate reservoirs in this study, yield smaller pore body sizes ( $T_{2lm} < 25$  ms), as well as narrower pore throats (average radius  $< 150$  nm) and lower permeability values (typically below 0.1 mD). The grainstone samples yield bimodal  $T_2$  distributions, with a first peak related to the cement matrix pores and a second peak related to intraparticle pores. The  $T_2$  distributions of limestone with fractures reflecting larger pore sizes ( $T_{2lm} > 100$  ms) and higher permeability (up to 10 mD). Additionally, each rock type's NMR characters were tested under different pressure, and their sensitive responses were also analyzed, especially for the second peak of grainstone and limestone with fractures.

The study aims to develop an NMR-based approach to characterize various carbonate rock-types, calibrated by geological and petrophysical analysis. The results allow an in depth understanding of the NMR signal of each carbonate rock type, and can be used as a guide to interpret NMR logging data.

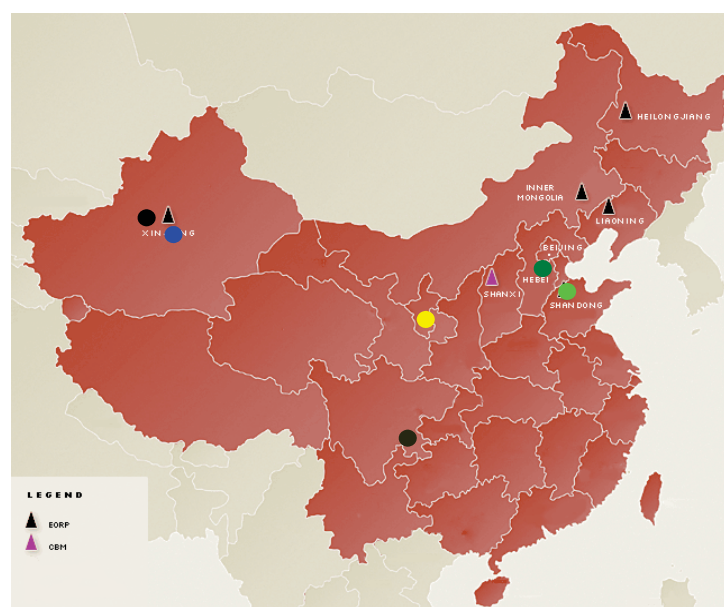
## 1 Introduction

- Hydrocarbon exploration practices around the world have demonstrated that deep layers of basins (those at depths  $> 4,500$  m) likely contain abundant hydrocarbon resources
- China has also initiated many oil and gas explorations in deep layered strata, e.g. Tarim, Sichuan, Bohai Bay Basins
- Inherently complex and heterogeneous lithologies of carbonates make characterizing them a real challenge
- Geological & petrophysical analysis can reveal pore structures
- The pore structure is a key parameter for knowing carbonate
- Geological analysis:  
Core samples, Thin section, Scanning Electron Microscope...
- Petrophysical analysis:  
Porosity, Permeability, Nuclear Magnetic Resonance (NMR)...
- NMR: Rapid, Non-Destructive, High Efficient and Economic...



Asia-Pacific	3103 Bonaparte
3004 Songliao	3105 Browse
3005 Yitong graben	3107 North Carnarvon
3010 Bohaiwan	3124 Taranaki
3017 Turpan	
3019 Junggar	Europe
3021 Tarim	4004 Voring
3023 Lunpola	4006 North Sea graben
3024 Sichuan	4008 Northwest German
3036 Hokkaido	4010 Finnoscandian border-
3037 Akita-Niigata	Danish-Polish margin
3045 West Taiwan	4013 North Carpathian
3049 Beibu Gulf	4014 Vienna
3054 Assam	4015 Pannonian
3058 Indus	4017 Carpathian-Balkanian
3059 Bombay	4021 Ionian
3062 Krishna	4022 Sicily
3071 East Java	4024 Peri-Appenninic foredeep
3081 Brunei-Sabah	4025 Adriatic
3091 Mekong	4026 Po

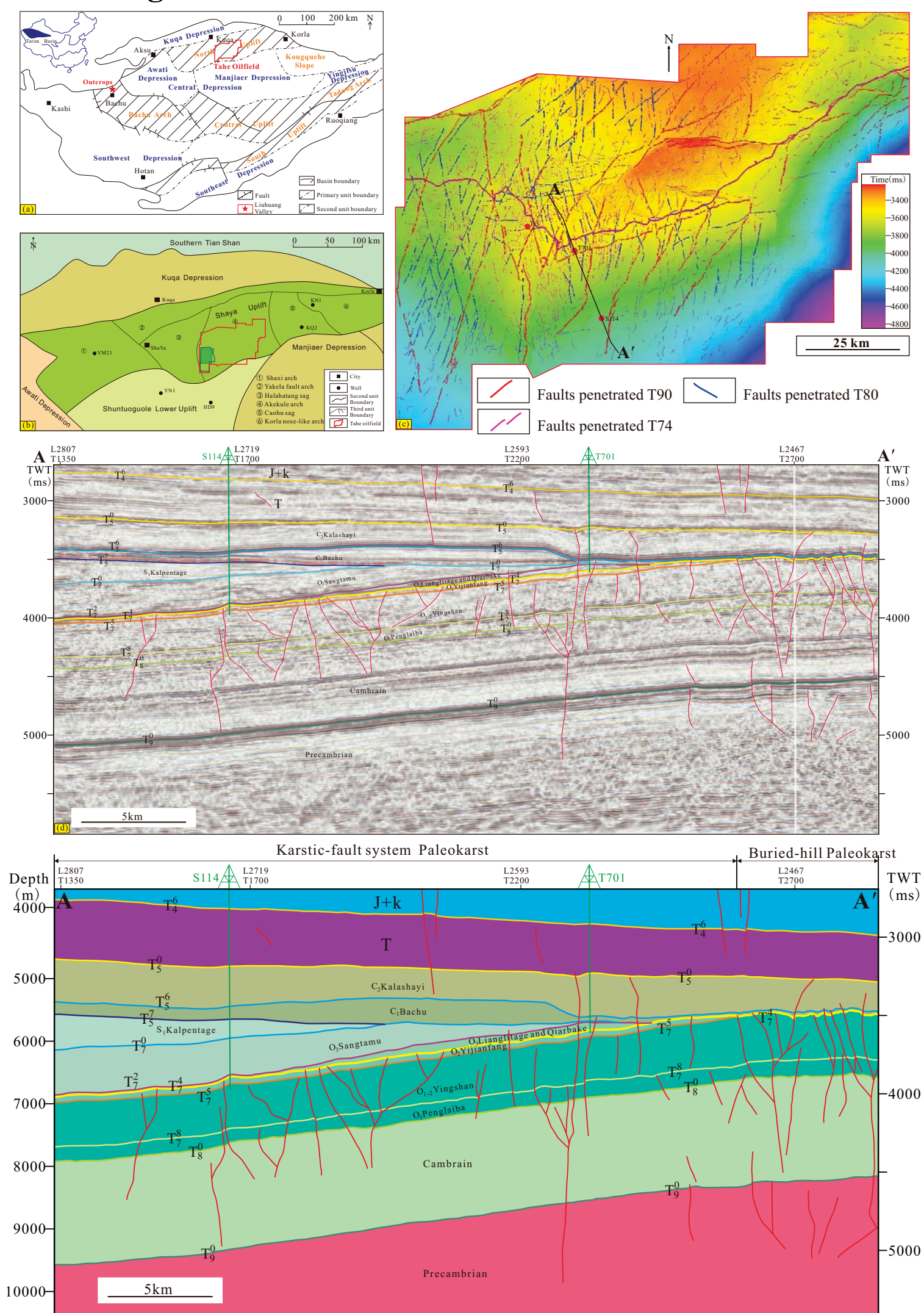
(Cao et al., 2013)



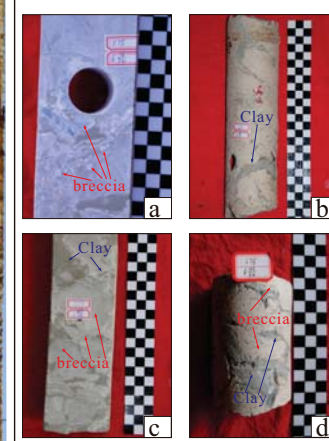
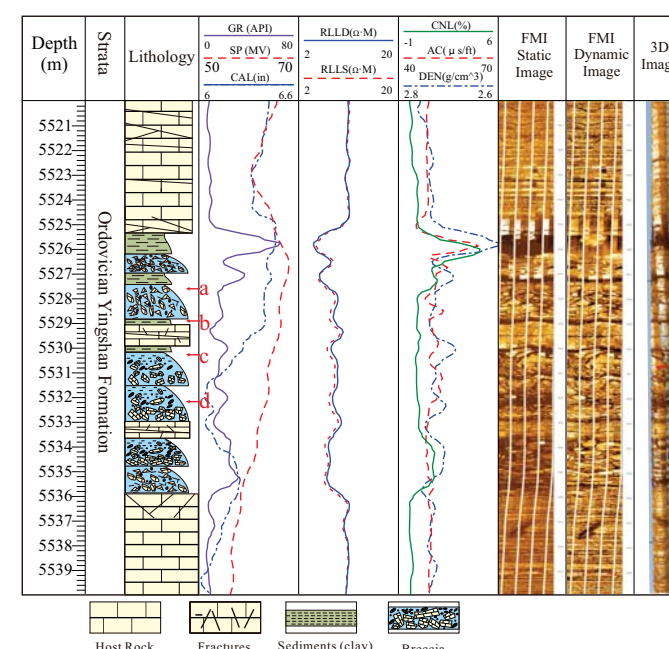
- Tarim Oilfield
- Tahe Oilfield
- Changqing Oilfield
- Shengli Oilfield
- Renqiu Oilfield
- Weiyuan Gasfield

## 2 Geological Setting

- Tahe Oilfield is the largest Chinese Paleozoic marine carbonate oilfield. The main formation of this oilfield is Ordovician strata, buried at a depth of more than 5,500 meters.
- In the northern region (main area) of the Tahe Oilfield, the main reservoirs are paleokarst reservoirs in the Lower- to Middle-Ordovician Yijianfang and Yingshan Formations.
- In the southern region of Tahe Oilfield falls within the peripheral slope area, and its Lower- to Middle-Ordovician strata are covered by nearly insoluble Upper Ordovician strata, including carbonate mudstones.



- Caves and vugs are the main storage spaces in Tahe Oilfield

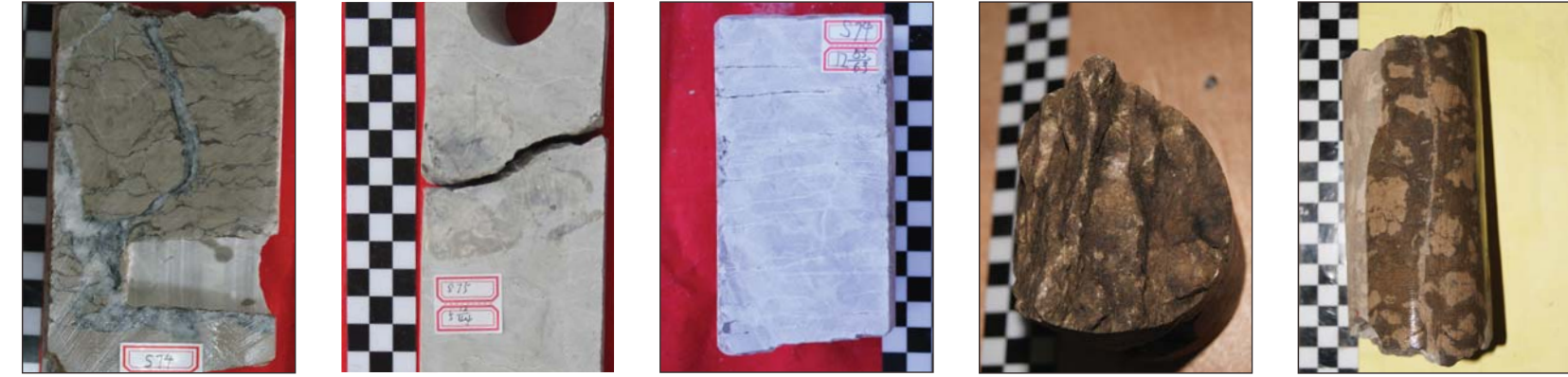


● How about the host rocks? Is there some storage in them?

3 Materials and Methods

3.1 Sampling

- Fouce on the tight carbonate area, avoiding the caves and fractures around the caves

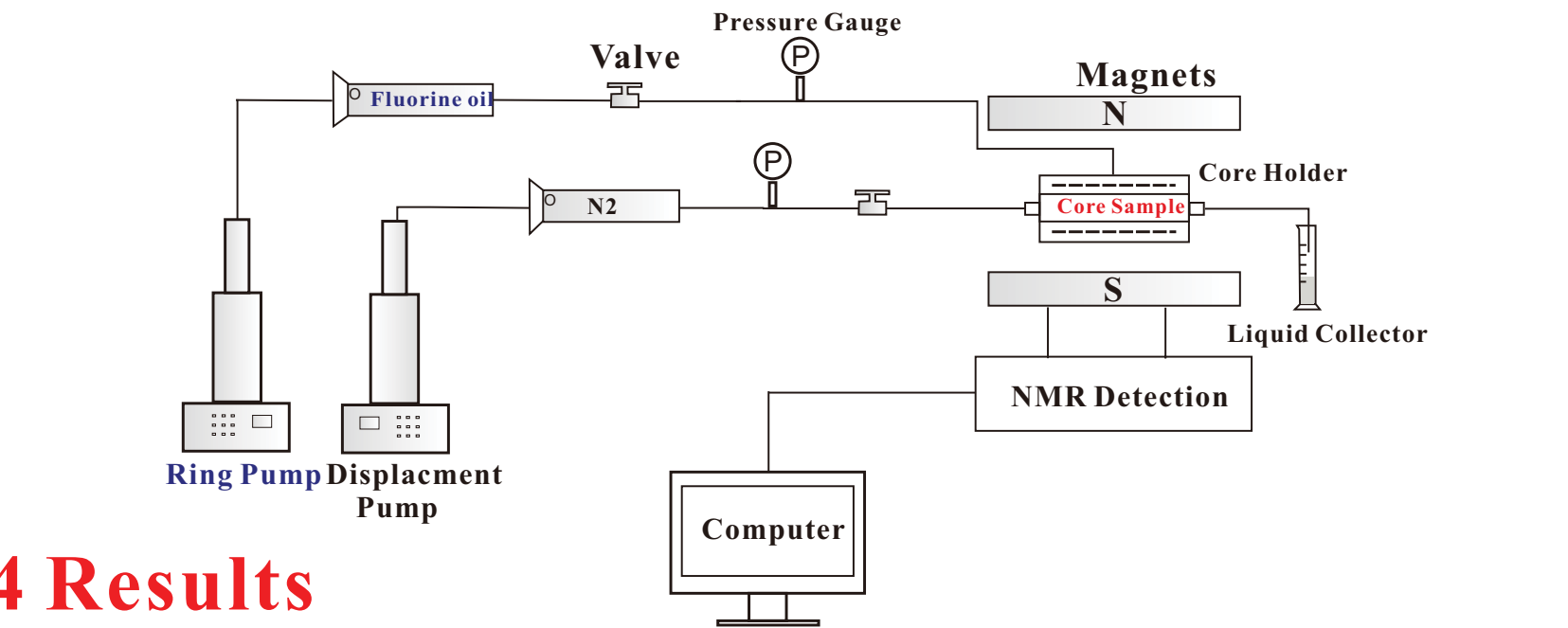


3.2 Petrography

- Dunham Classification
- Mudstone, Wackstone, Packstone, Grainstone
- Half-filled fracture
- Full-filled fracture

3.3. Petrophysics

- (1)Porosity and permeability
- (2)Mercury injection capillary pressure (MICP)
- (3)Nuclear Magnetic resonance (NMR)



4 Results

4.1 Petrography

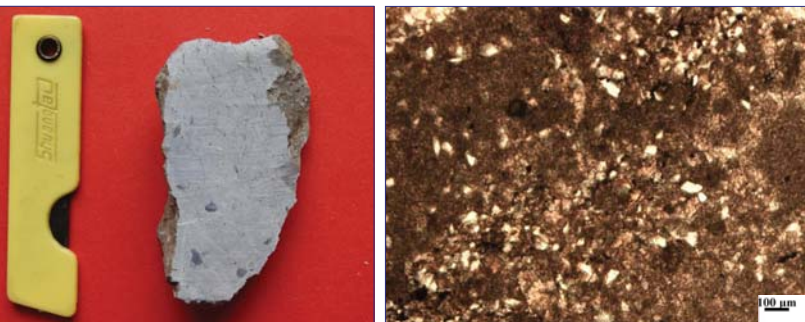
(1) Mudstone

Mudstone is mainly composed of carbonate lime mud with particles smaller than 10 μm. This mudstone formed in quiet hydrodynamic conditions and mostly occurs in the subfacies of lagoons, intra-platform depressions, lime mud mounds, and interbank seas. Thin sections reveal no evidence of mudstone dissolution.



(2) Wackstone

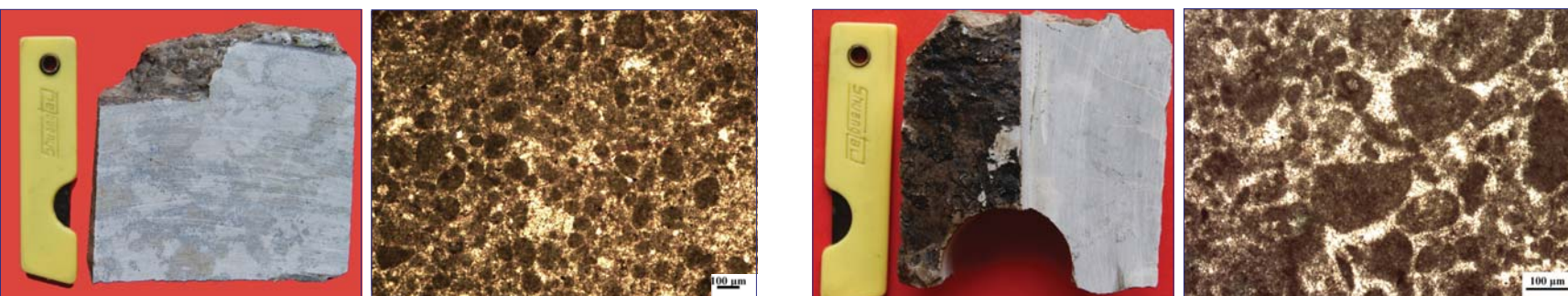
Wackstone is formed in sedimentary subfacies, such as the intra-platform gentle slope and the intra-platform shoal. It consists primarily of carbonate lime mud and contains some particles. In the observed cores, most wackstone is dense , but some contains open fractures.



(3) Packstone

Packstone forms within sedimentary subfacies, such as tables, platform internal reefs, and grain shoals. It is primarily granular to inter-granular, with plaster filler.

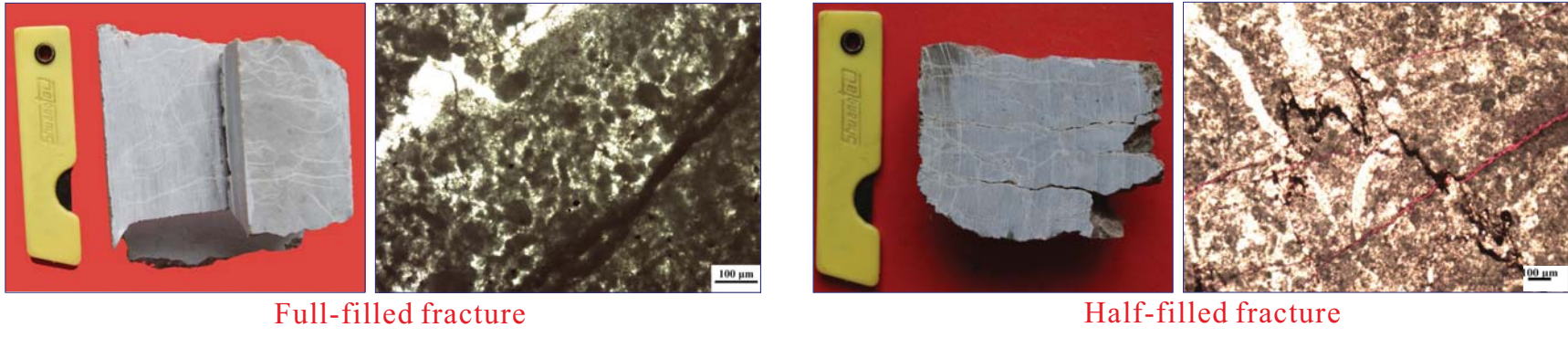
Grainstone is dominated by grain-supported, sparry calcite that fills the spaces between particles. It forms within sedimentary subfacies produced in high hydrodynamic conditions, such as intra-platform shoals and grain shoals. The particles and sparry cement in granular limestone can easily be dissolved by meteoric water, thus forming the intra-granular and inter-granular dissolution vugs that represent the most ideal hydrocarbon reservoir spaces within the study area.



(4) Grainstone

- (5) Limestone with full-filled fracture
- (6) Limestone with half-filled fracture

The diagenesis processes in the carbonate rocks, including dissolution and precipitation, occured frequently.In the groundwater flow active horizon of the cracks are open, while in the horizon groundwater stagnant flow state, crack is easy to pack by late calcite.

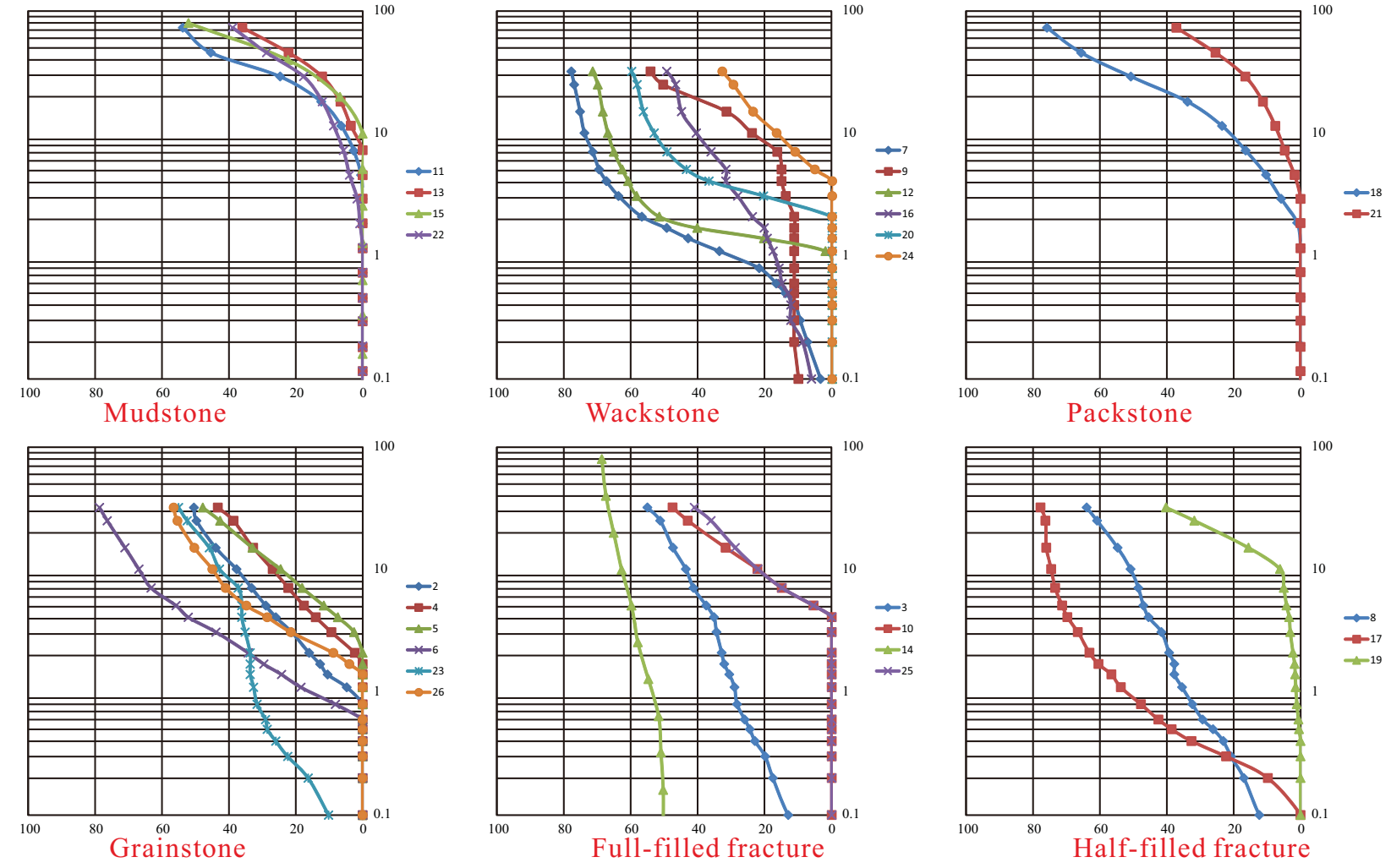


4.2 Petrophysics

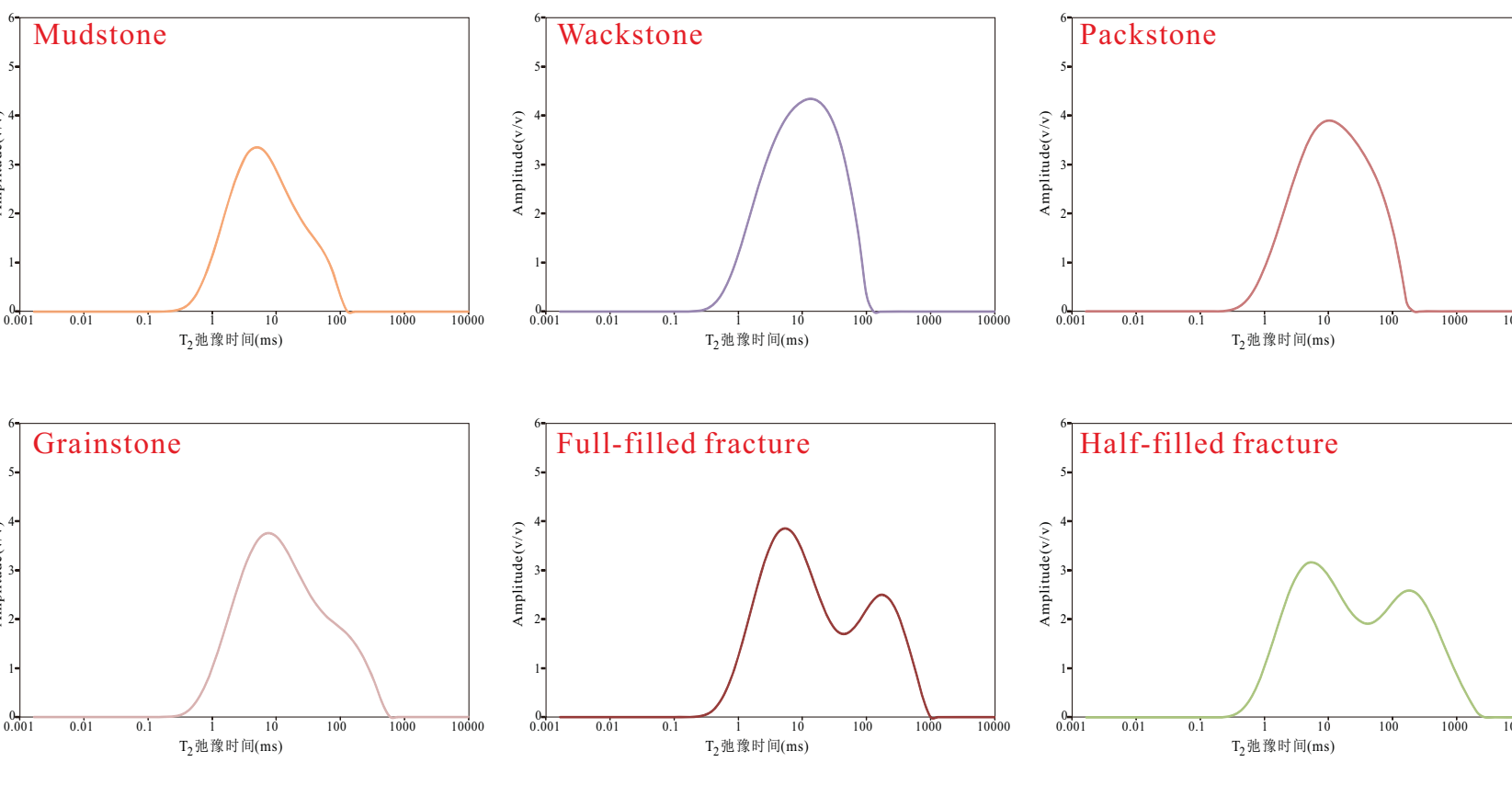
(1) Porosity and permeability

Rock Type	Sample Number	Length/cm	Diameter/c m	Density/g* cm-3	Porosity/%	Permeabilit y/mD
Mudstone	11	4.372	2.45	2.67	0.79	0.002
	13	4.15	2.52	2.7	0.51	0.009
	15	4.259	2.53	2.67	0.63	0.009
	22	4.133	2.53	2.67	0.75	0.01
Wackstone	7	4.292	2.46	2.67	0.82	0.24
	9	4.534	2.52	2.68	0.53	0.03
	12	4.398	2.53	2.66	0.68	0.12
	16	4.302	2.53	2.68	0.76	0.2
	20	4.425	2.52	2.68	0.55	0.05
Packstone	24	4.447	2.53	2.68	0.53	0.02
	18	4.462	2.53	2.67	1.23	0.01
Grainstone	21	3.72	2.52	2.67	1.37	0.01
	2	5.045	2.48	2.67	0.95	0.06
	4	4.395	2.53	2.66	0.89	0.15
	5	3.953	2.52	2.67	0.82	0.07
	6	4.385	2.53	2.66	0.9	0.2
	23	4.464	2.53	2.65	1.31	0.39
Limestone with full-filled fractures	26	4.418	2.53	2.65	1.17	0.28
	3	4.533	2.53	2.67	0.83	0.44
	10	4.368	2.53	2.68	0.56	0.11
Limestone with halg-filled fractures	14	4.293	2.53	2.67	0.53	0.2
	25	4.408	2.53	2.66	0.44	0.05
	8	4.992	2.48	2.64	2.15	4.36
	17	4.106	2.53	2.65	1.89	1.69
	19	4.347	2.52	2.65	1.67	1.28

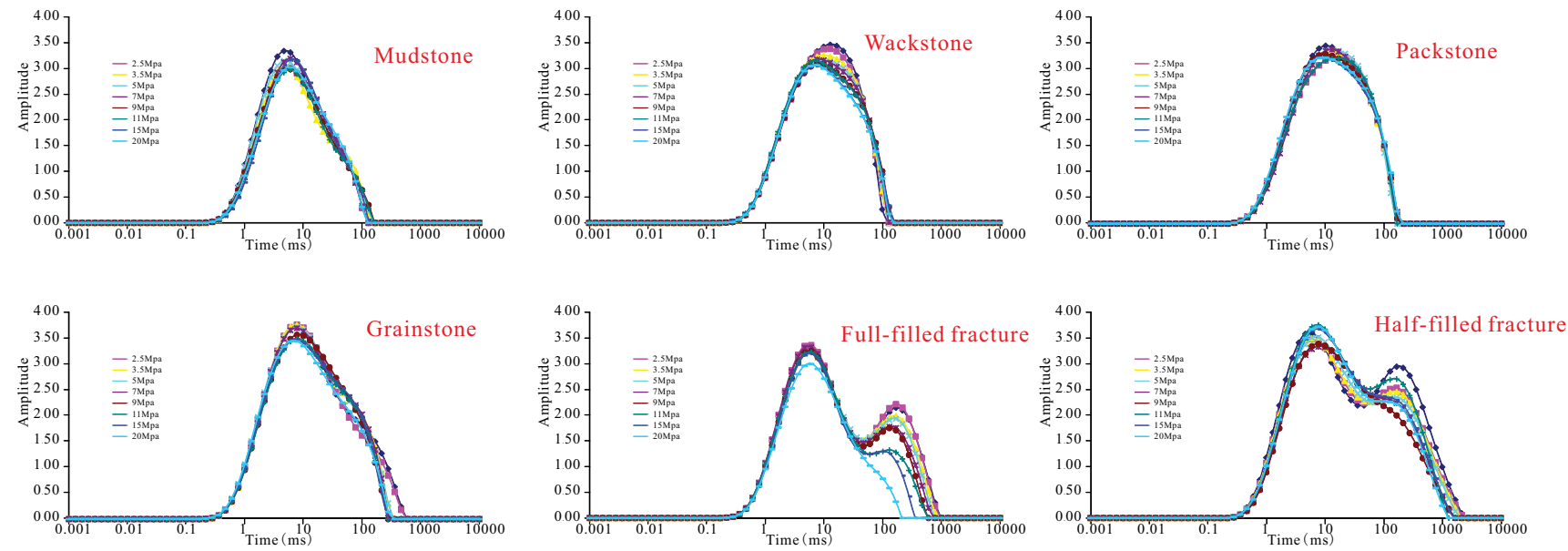
(2) Mercury-injection capillary pressure (MICP)



(3) Nuclear Magnetic Resonance (NMR)

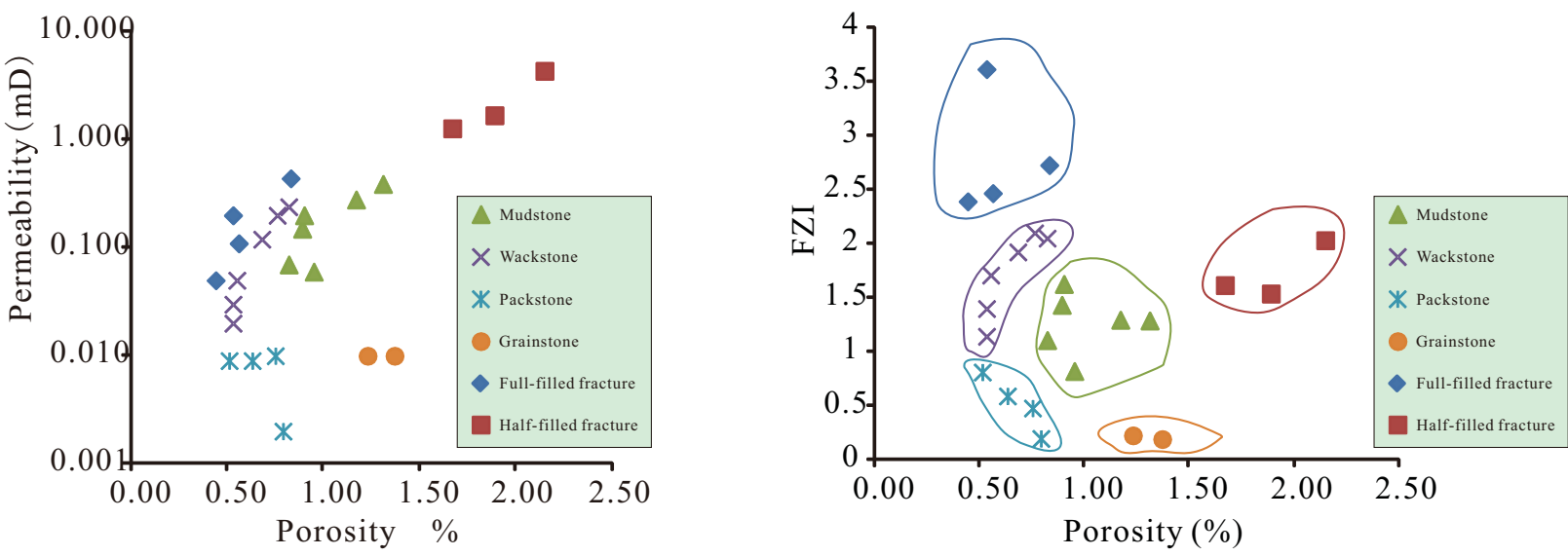


(4)NMR Under Pressure

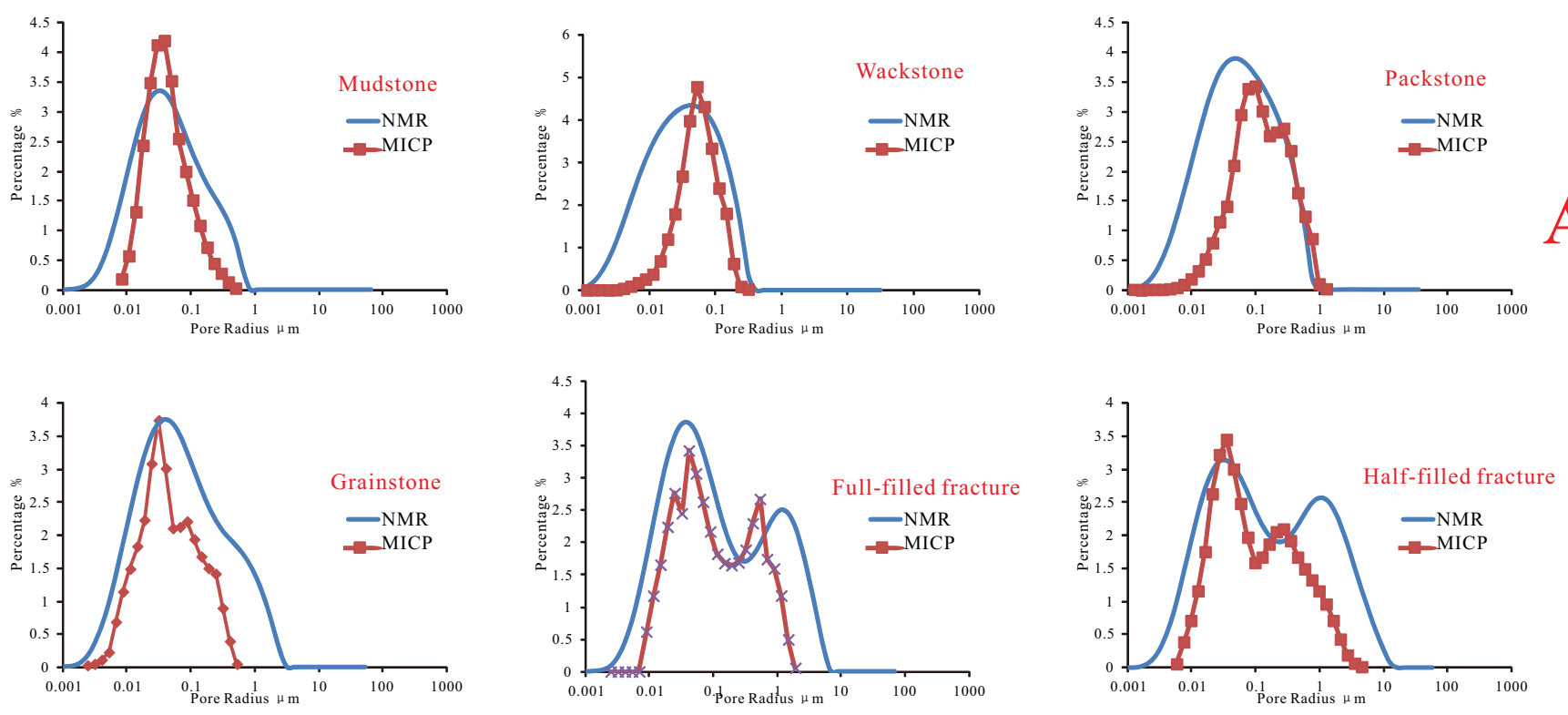


5 Discusion

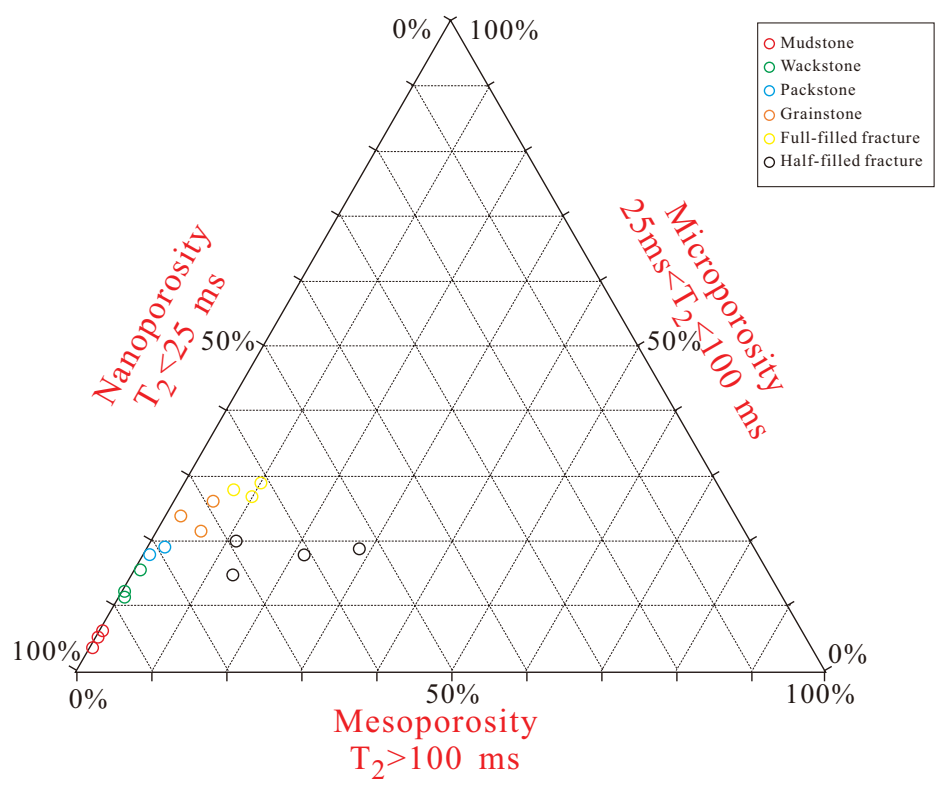
5.1 Porosity and permeability of different rock types



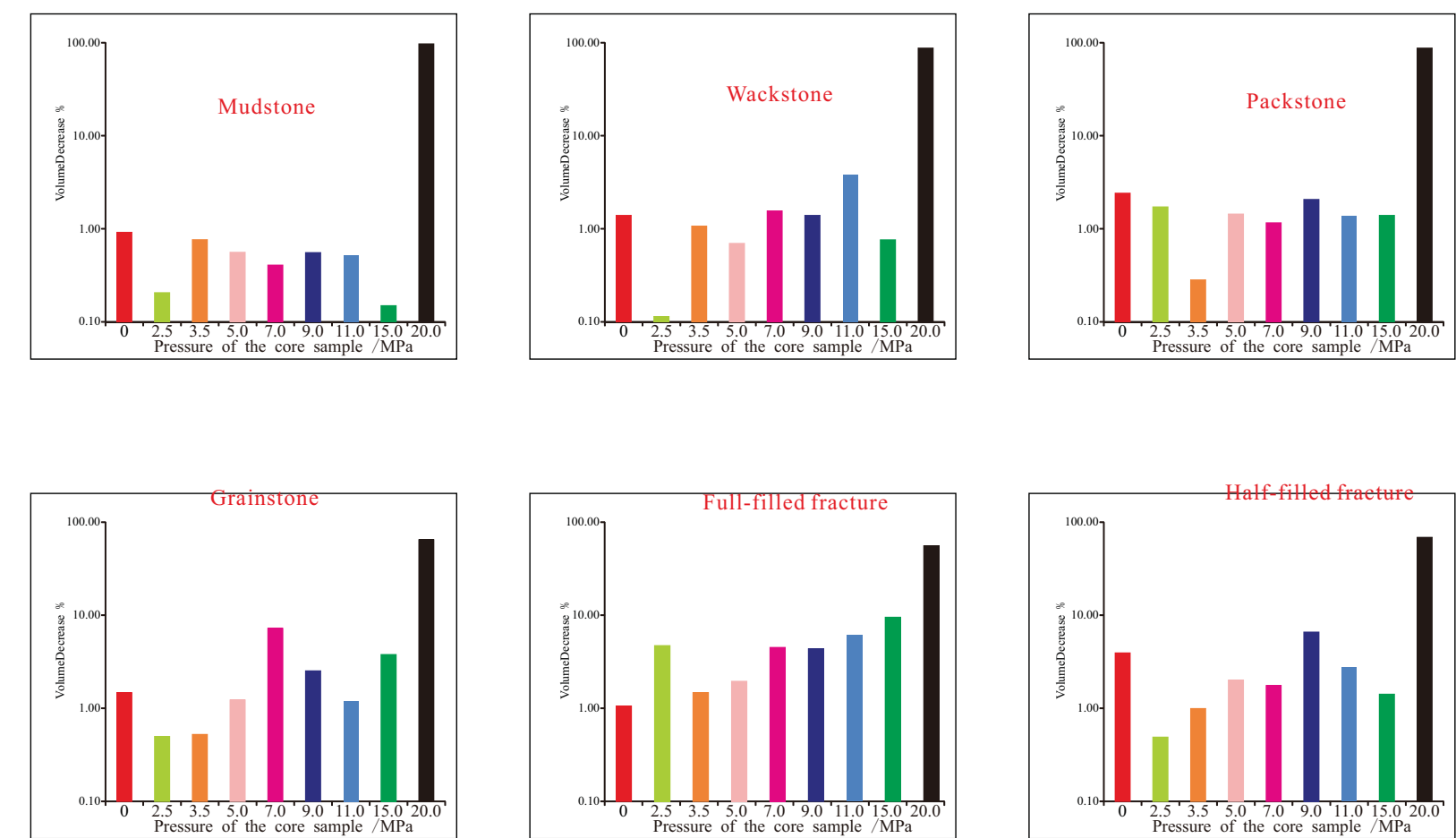
5.2 MICP and NMR



5.3 NMR of different rock types



5.4 Pore Decrease Under Pressure



6 Conclusion

(1)Based on Core samples observations and thin section observations, six rock types were divided in this study, including mudstone, wackstone, packstone, grainstone, Limestone with full-filled fracture, Limestone with half-filled fracture.

(2)Through the testing of nuclear magnetic resonance (NMR) characteristics of each rock type, we get their T2 spectrum. Combined with the feature of mercury injection, and then got the different pore size distribution of rock facies. Aperture and further divided into the large pore diameter and pore diameter and small aperture.

(3) Packstone, wackstone and mudstone of the carbonate yield smaller pore body sizes (T2lm < 20 ms), as well as narrower pore throats (average radius < 150 nm) and lower permeability values (typically below 0.1 mD). The grainstone samples yield bimodal T2 distributions, with a first peak related to the cement matrix pores and a second peak related to intraparticle pores. The T2 distributions of limestone with fractures reflecting larger pore sizes (T2lm > 90 ms) and higher permeability.

Acknowledgements

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