Quantitative Microporosity Evaluation Using Mercury Injection and Digital Image Analysis in Tight Carbonate Rocks: A Case Study From the Ordovician in the Tazhong Palaeouplift, Tarim Basin, NW China*

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Abstract

The heterogeneity of tight carbonate rocks is directly related to the morphology of micropores and the connectivity of the pore network, which have a great influence on the intrinsic microporosity and fluid flow properties of porous media. However, neither can be quantitatively evaluated by conventional techniques. Based on core observation and thin section analysis, combined with high-resolution field emission-scanning electron microscopy (FE-SEM) and mercury injection capillary pressure (MICP) measurements, we can identify carbonate rock types, determine the microporosity and microstructure and calculate the pore structure parameters. Digital image analysis (DIA) and the fractal dimension (FD) method are used to study the relationship between the quantified pore structure parameters, heterogeneity and fluid flow properties. The results indicate that rock types in 12 carbonate samples are dominated by grainstone and packstone, followed by wackestone and dolomitic packstone. The microporosity of rock types has various microstructure characteristics. Crystalline types of microporosity (the small and large intercrystalline pores) increase pore network connectivity whereas micromoldic pores show variations in connectivity of different lithofacies. However, the small intercrystalline pores contribute little to the permeability because of narrow and complex pore networks for fluid flow. MICP data of samples reveal that the pore-throat radius mainly ranges from 0.1 μm to 1.0 μm, which contributes the highest proportion of permeability to the samples. Fractal dimensions calculated from the “J-curve” models vary between 2.0746 and 2.8551 (avg. 2.331), indicating high heterogeneity. Moreover, the fractal dimension is strongly negatively related to the permeability, average pore throat radius and separation coefficient. Additionally, quantified pore geometric parameters from DIA, including dominant pore size (DOMsize), perimeter over area (PoA), pore body-to-throat ratio (BTR) and average roundness (γa), greatly influence the pore structure and fluid flow behavior. The samples with large DOMsize, high γa, low PoA and low BTR show a low fractal dimension and simple pore network but high permeability. Diagenesis can also affect the fractal pore space and self-similarity pore geometries of carbonates across all length scales. This information about the micropore geometry and microstructure of the carbonate rock will further improve the assessment of its reservoir properties.

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Quantitative microporosity evaluation using mercury injection and digital image analysis in tight carbonate rocks: A case study from the Ordovician in the Tazhong Palaeouplift, Tarim Basin, NW China

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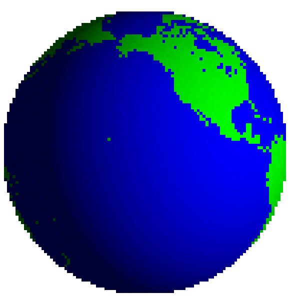

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Outline

- Introduction
- Objectives and methods
- Results and discussion
- Conclusion

➢Introduction

1.ONE

Heterogeneity of tight carbonate rocks is directly related to the morphology of micropores and the connectivity of the pore network. But both can't be quantitatively evaluated by conventional techniques.

2.TWO

MICP methods were effectively applied to characterize the size, shape and distribution of pore throat and evaluate pore structure**.** The combination of high-quality SEM mosaics with auto-optical micrographs provides a DIA for evaluating mineral structures and quantifying pore system under a microscopic or nanoscopic scale

3.THREE

Quantitative evaluation of pore structure is important to understanding the relationship between pore geometry features and fluid flow properties in reservoir

Outline

Introduction

Objectives and methods

Results and discussion

Conclusion

➢Objectives and methods

- ◆ evaluate the lithofacies, microporosity, and microstructure characteristics of the Ordovician tight carbonate rocks in Tazhong area

- ◆ characterize pore structure and fractal dimension from MICP measurements

- ◆ determine the pore geometric parameters from DIA

- ◆ study the relationship between fractal dimension and pore structure parameters form MICP and DIA

Objectives and methods

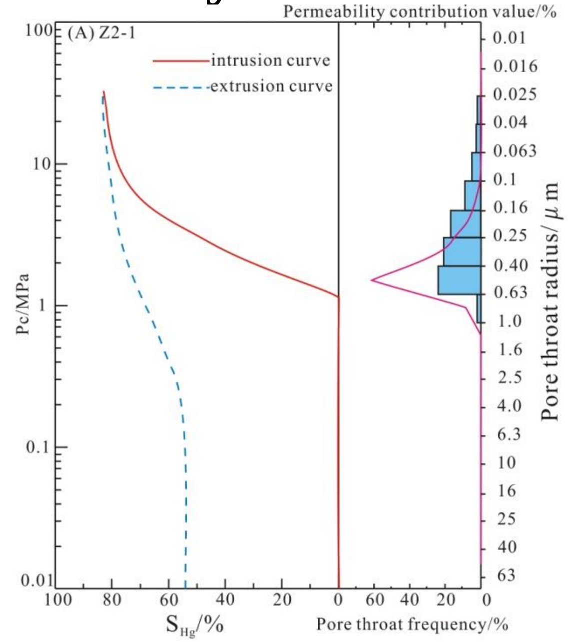
1. Porosity, pore structure and permeability measures

$$R = -\frac{2\sigma\cos\theta}{P_c}$$

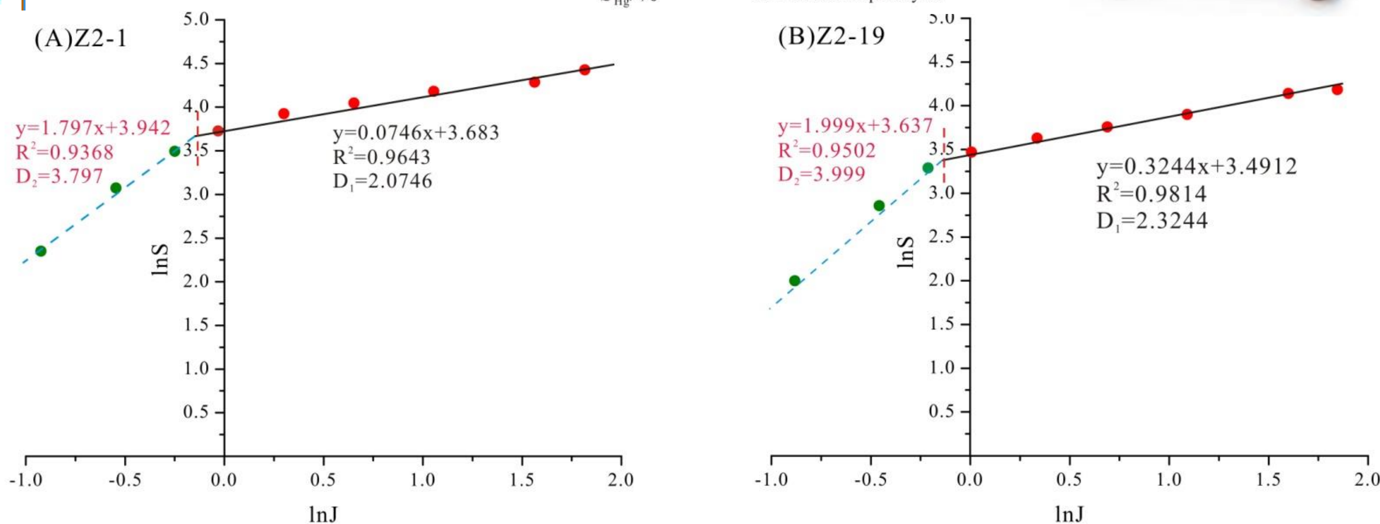
$$We = \frac{S_{max} - S_{Hgr}}{S_{max}} \times 100\%$$

$$Sp = \left[\frac{F(-\log 2R - Ra)^2}{100}\right]^{1/2}$$

$$\ln S = \frac{2-D}{2}\ln\left|\frac{f(3-D)}{2(5-D)}\right| + A\ln J$$



Fractal dimensions from mercury intrusion capillary tests



➢Objectives and methods

2.Digital image analysis

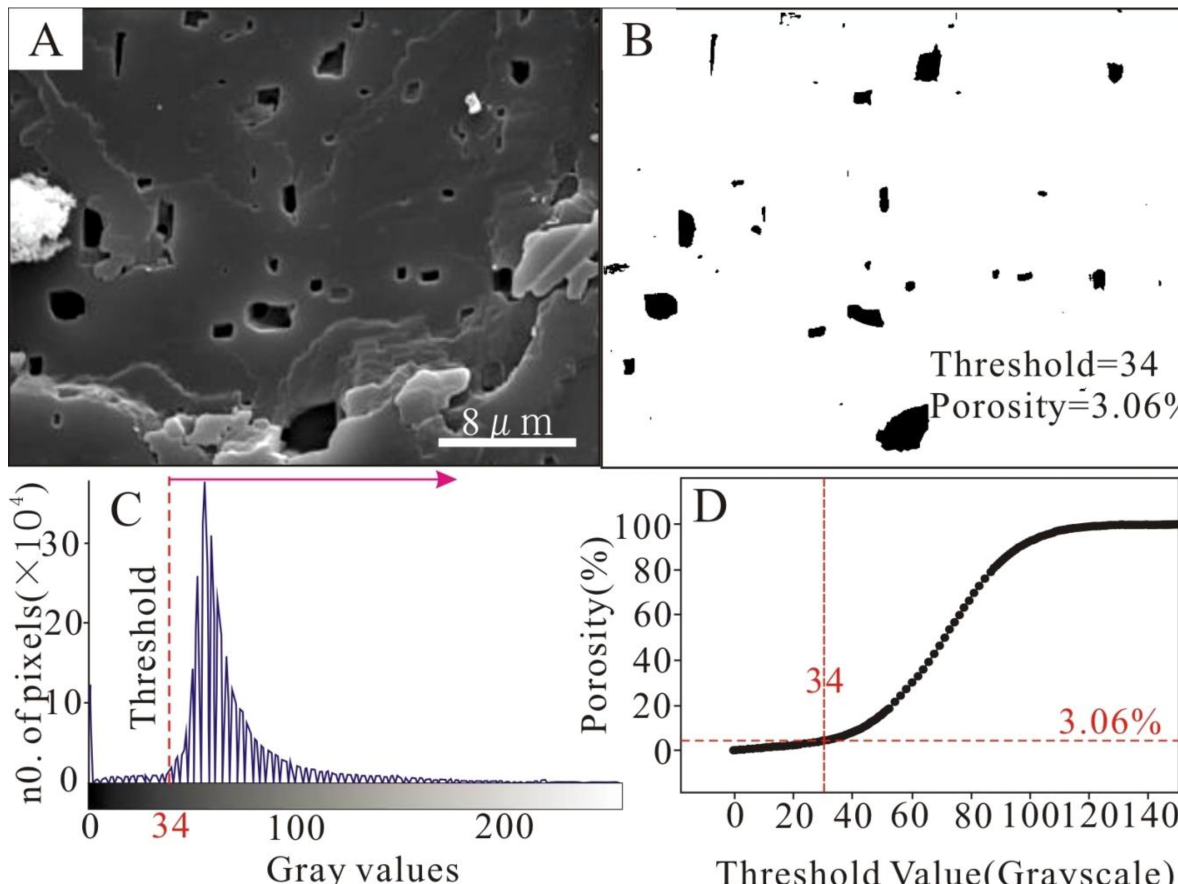
$$Phi_{TS/SEM} = \frac{Pore_{TS/SEM}}{Area_F} \times 100\%$$

$$PoA = \frac{1}{3}\left(\frac{\sum Perimeter_{TS}}{\sum Area_{TS}} + \frac{\sum Perimeter_{SEM0.5K}}{\sum Area_{SEM0.5K}} + \frac{\sum Perimeter_{SEM1.5K}}{\sum Area_{SEM1.5K}} \right)$$

$$BTR = \frac{DOMsize}{2R}$$

$$\gamma = \frac{P}{2\sqrt{\pi A}}$$

$$\gamma_a = \frac{\sum_i (A_i \times \gamma_i)}{\sum_i A_i}$$



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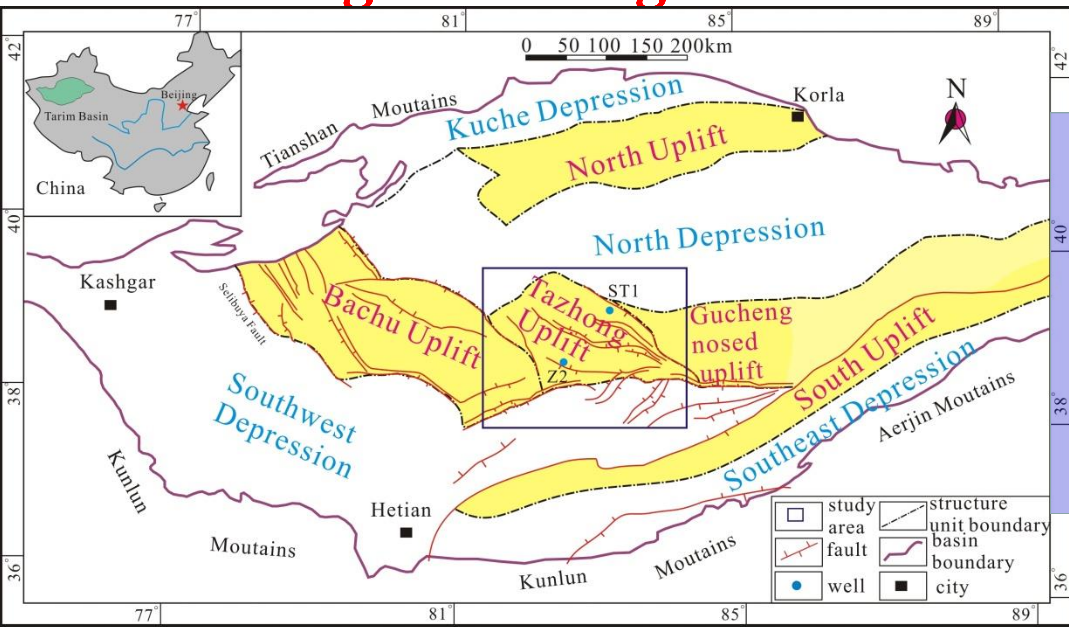
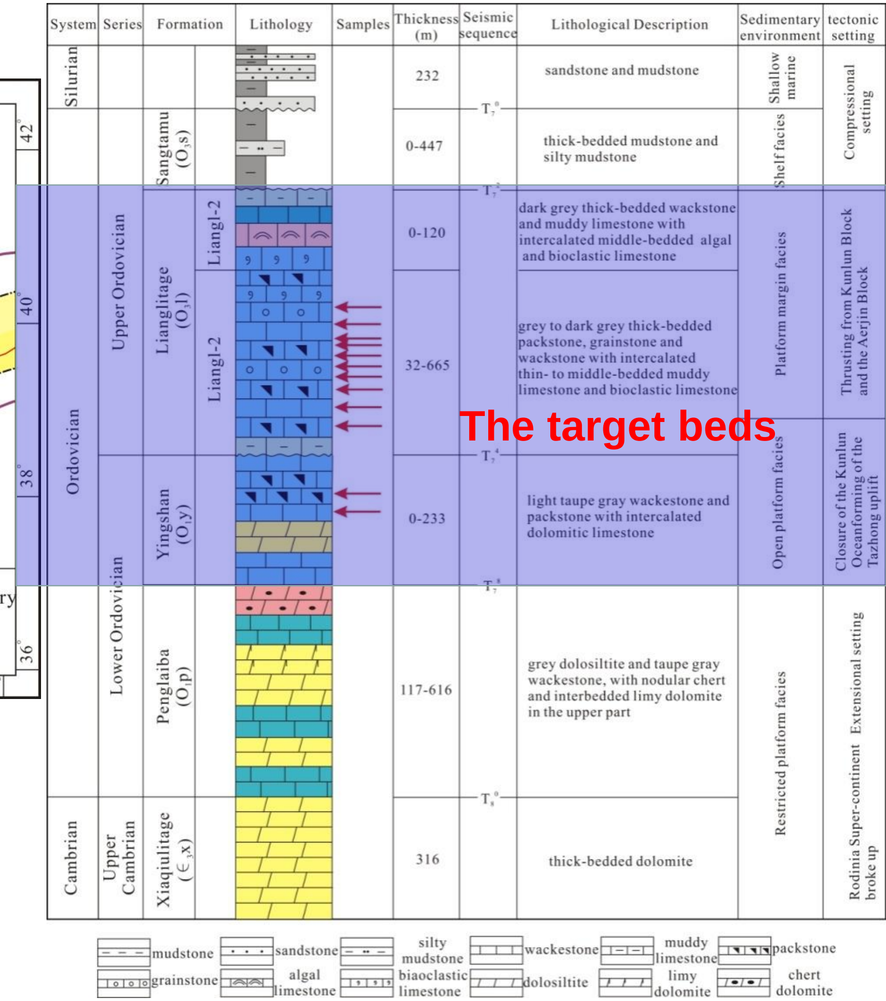
➢Results and discussion

Geological setting



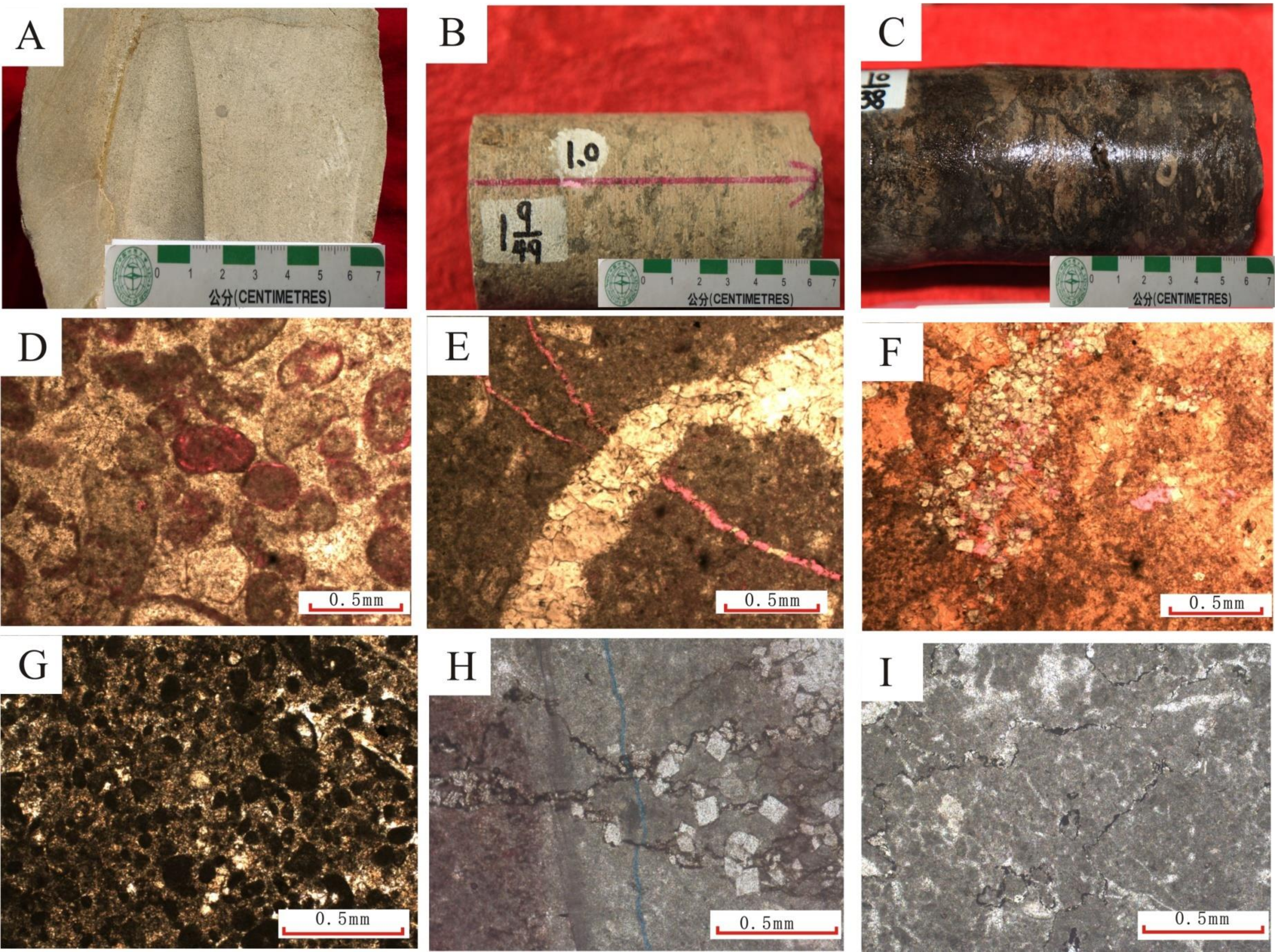
Location of the study area

The Lianglitage Formation is dominanted by platform margin sediments, harboring thick-bedded packstone, grainstone and muddy limestone . The Yingshan Formation is composed mainly of open platform deposites, with light gray or gray packstone, wrackstone, and dolomitic limestone .



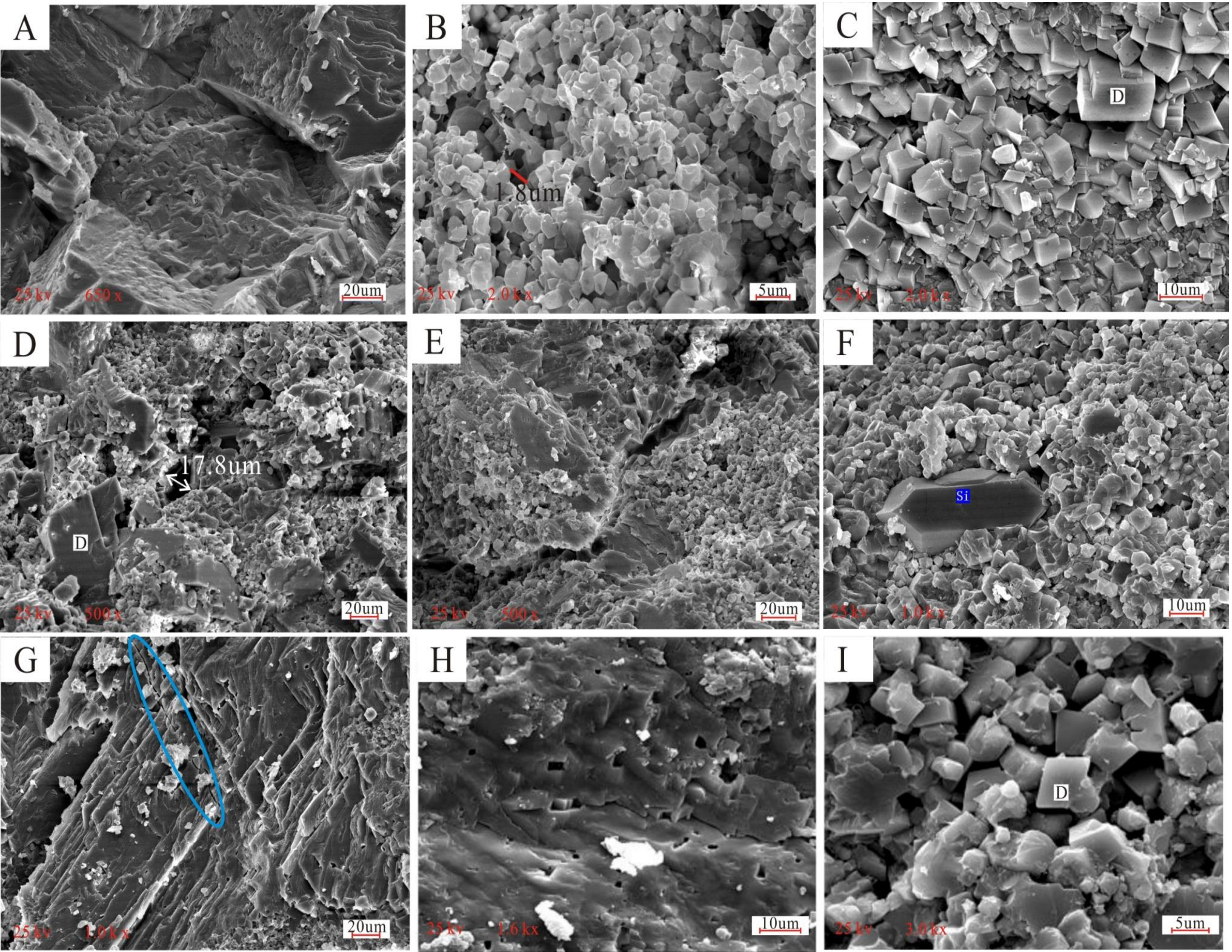
Tertiary stratigraphy of the area

➢Results and discussion



A.Grainstone
B.Packstone
C.Wackestone
D.Grainstone
E.Wackestone
F.Dolomitic packstone
G.Packstone
H.Packstone
I.Wackestone

➢Results and discussion



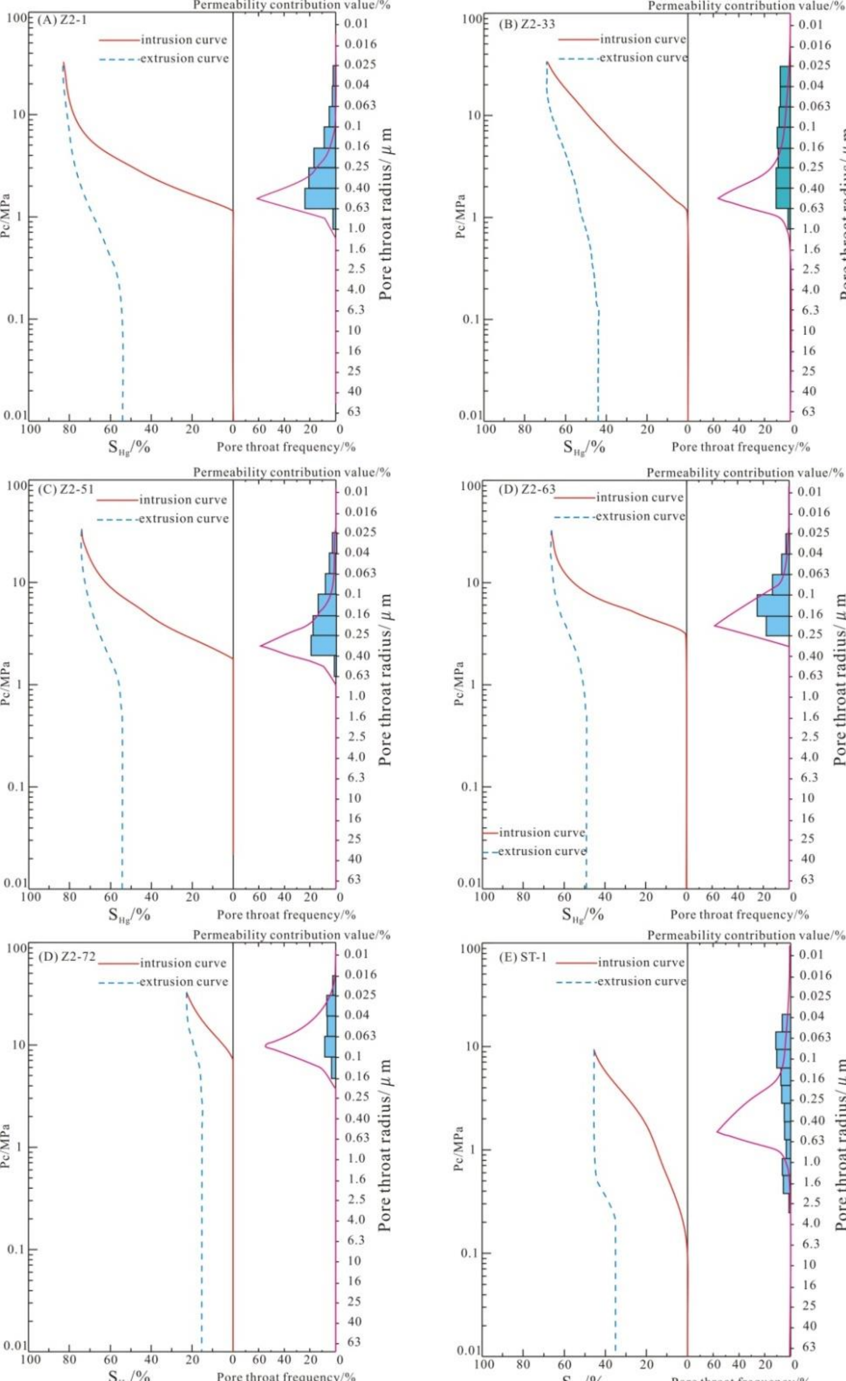
A.Intracrystal Moldic pore
B.Intercrystalline pore
C.Intercrystalline pore
D. Moldic pores
E. Half-filled dissolved fracture
F.Dolomitic packstone
G. Small intercrystalline pores
H. Micropores
I.Intercrystalline micropore

➢Results and discussion

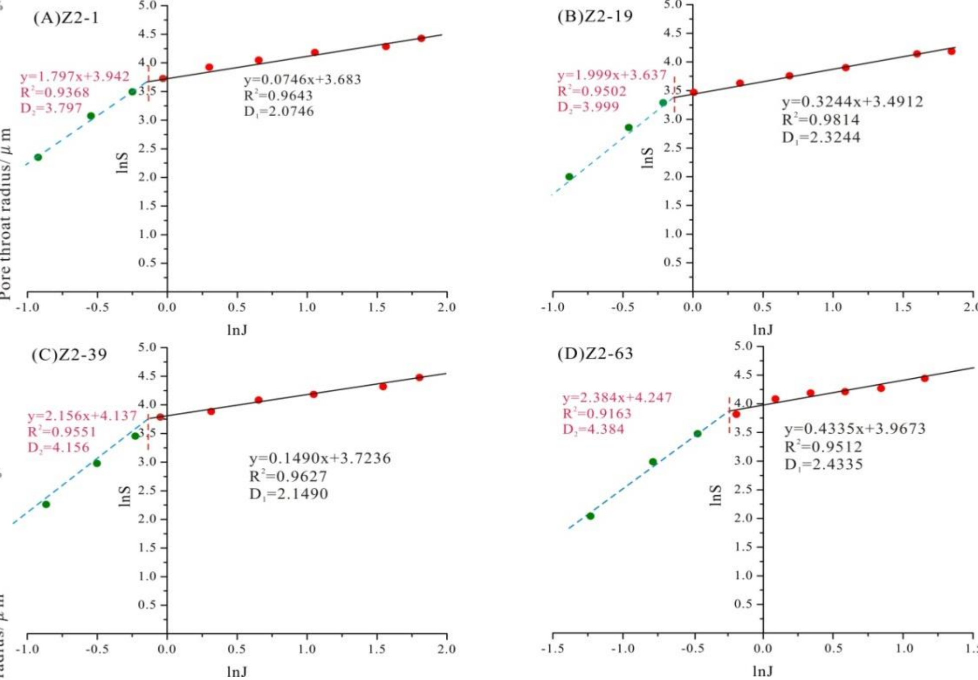
Table. 1 Quantitative petrophysical, fractal dimensions and pore-structural parameters of 12 analyzed carbonate plug samples

Samples	Lithology	Dominant Pore type	Minor Pore Type	Mercury Injection Measure									Digital Image Analysis			
				Φ /%	K /mD	D	R^2	Rm /μm	Ra /μm	Sp	We /%	Vp /cm^3	POA /mm^{-1}	DOMsize /μm	BTR	γ_a
z2-1	G	MO	SI	5.8	0.679	2.0746	0.9643	0.649	0.239	0.72	42.06	0.784	1474.2	1.65	6.85	3.17
z2-12	W	SI	FR	4	0.433	2.4013	0.9974	0.213	0.069	1.21	27.95	0.444	2686	1.3	17.5	2.85
z2-19	W	SI	FR	4.4	0.241	2.3244	0.9814	0.441	0.137	0.97	43.84	0.282	3466.3	1.05	21.9	3.01
z2-33	D-P	LI	MO, SI	3.5	0.963	2.1975	0.9809	0.644	0.157	0.90	51.78	0.357	1380	1.84	8.4	3.52
z2-39	D-P	LI	MO, SI	5.3	0.57	2.1490	0.9627	0.406	0.133	0.87	41.06	0.619	1557.3	1.6	10.7	3.61
z2-46	G	MO	FR,SI	4.6	1.26	2.0940	0.9956	0.544	0.205	0.78	51.25	0.61	1086	2.23	9.8	4.2
z2-51	G	MO	SI	5.1	0.191	2.1993	0.9715	0.418	0.139	1.09	35.89	0.686	1842.9	1.07	6.17	1.81
z2-63	P	SI	MO	4.6	0.033	2.4335	0.9512	0.226	0.095	1.31	39.25	0.619	2285.7	0.69	12.1	1.54
z2-72	W	SI		1.4	0.008	2.8551	0.9710	0.105	0.038	1.44	22.98	0.192	3658.3	0.93	24.7	1.47
z2-87	P	SI	FR	0.83	0.17	2.5108	0.9993	0.129	0.046	1.15	23.08	0.113	3234.7	0.65	22.9	1.85
ST1-1	P	MO	SI, FR	2	0.85	2.2182	0.9553	1.231	0.149	0.95	22.89	0.279	2220.7	1.14	11.3	2.42
ST1-2	W	SI	MO	2.6	0.02	2.5084	0.9643	0.182	0.051	1.12	17.36	0.39	3707.6	0.74	14.5	1.89

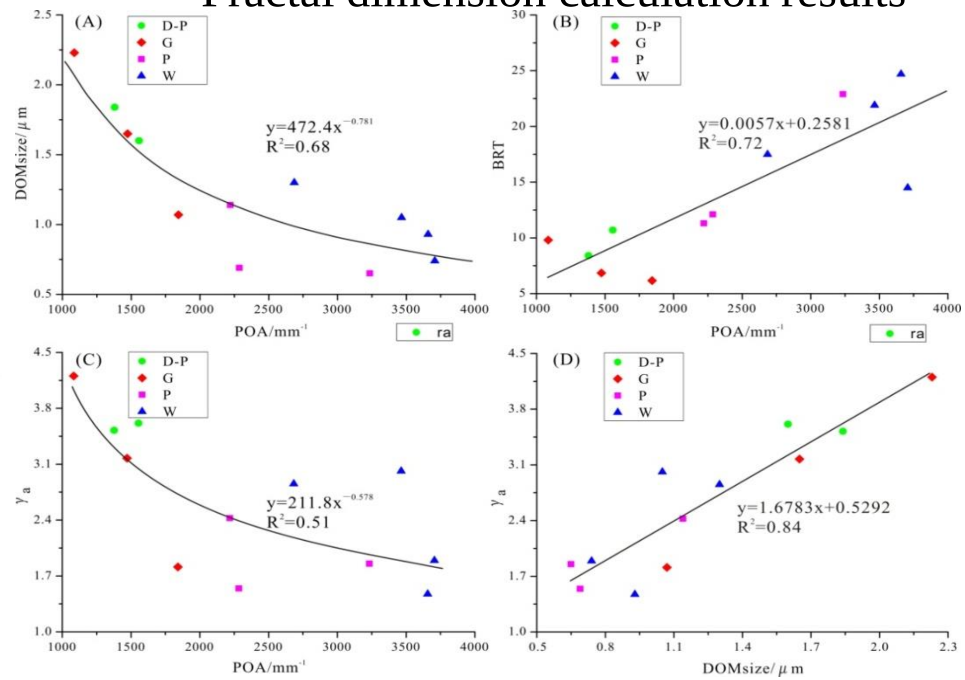
G: grainstone; D-P: dolomitic packstone; P: packstone; W: wackestone; SI: small intercrystalline; LI: large intercrystalline; MO: micromoldic; FR: fracture; D: fractal dimension; Rm: largest pore-throat radius; Ra: average porethroat radius; Sp: separation coefficient; We: ejection efficiency; Vp: total pore volume; PoA: perimeter over area; DOMsize: dominant pore area; BTR: pore body- tothroat ratio; γa: the average roundness; R^2: correlation coefficient.



Mercury injection porosimeter results



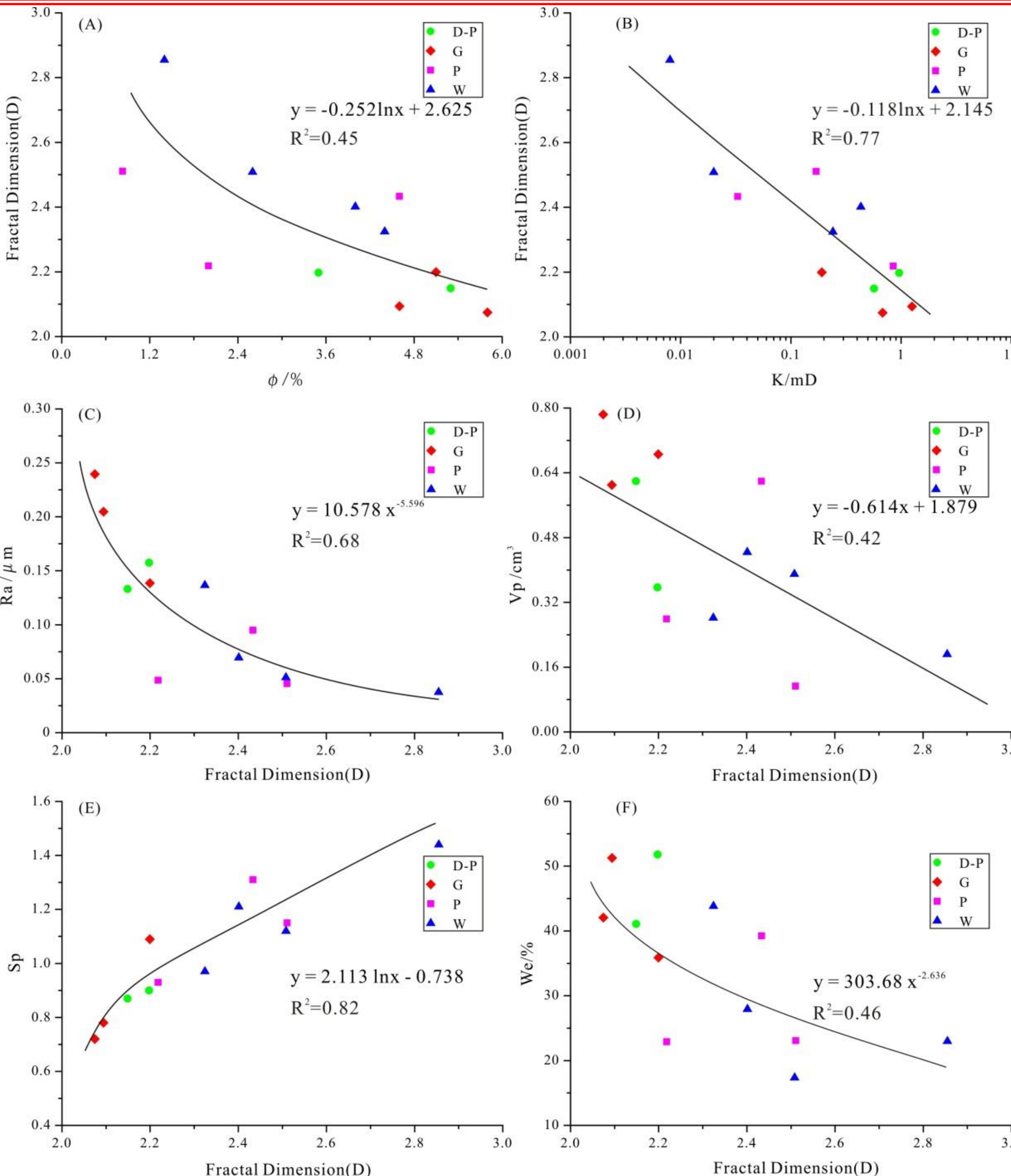
Fractal dimension calculation results

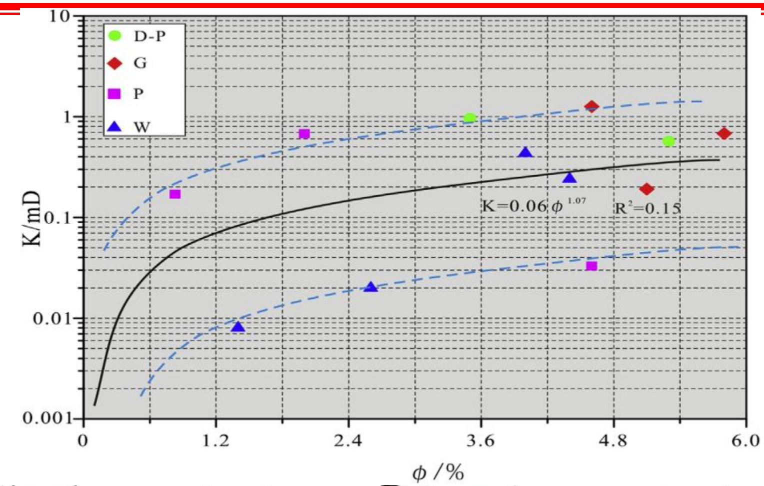


The relationship between the pore geometric parameters

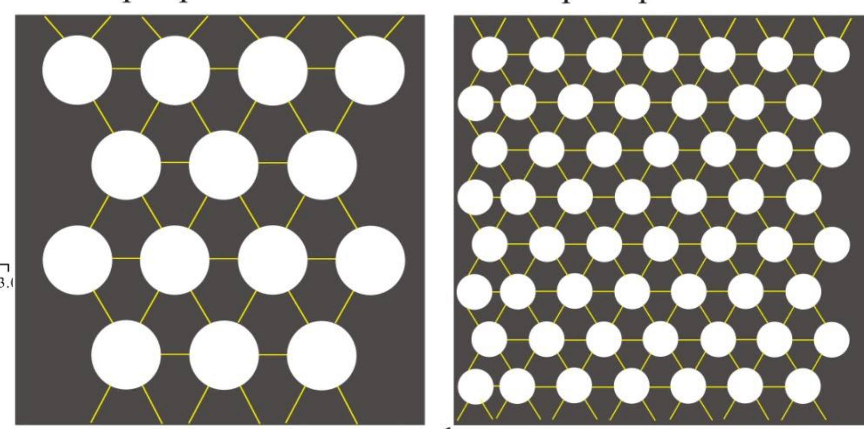
➢Results and discussion

Porosity, pore structure parameters and permeability relationships with fractal dimensions





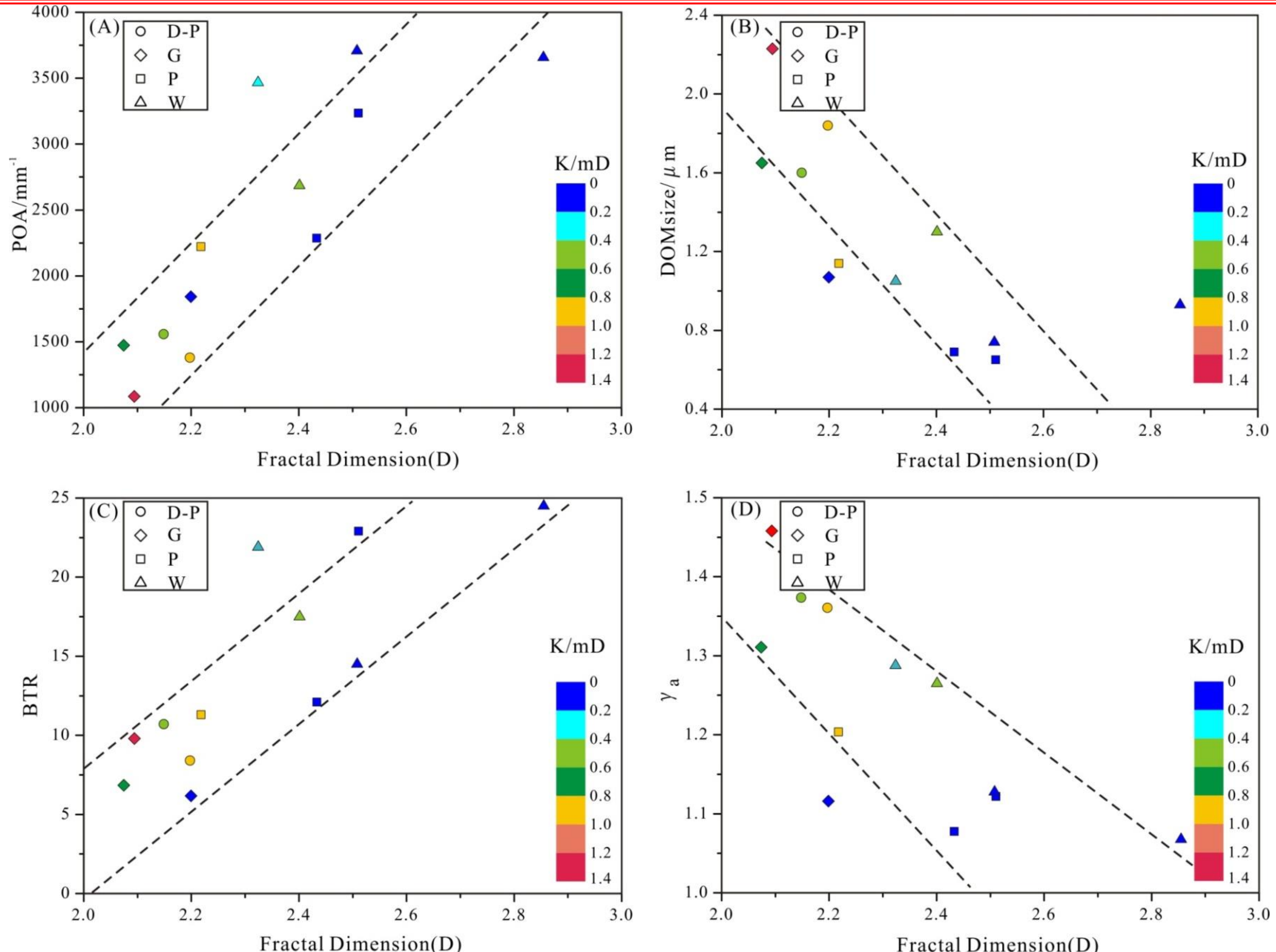
A Simple pore structure B Complex pore structure



5mm rock skeleton pore throat

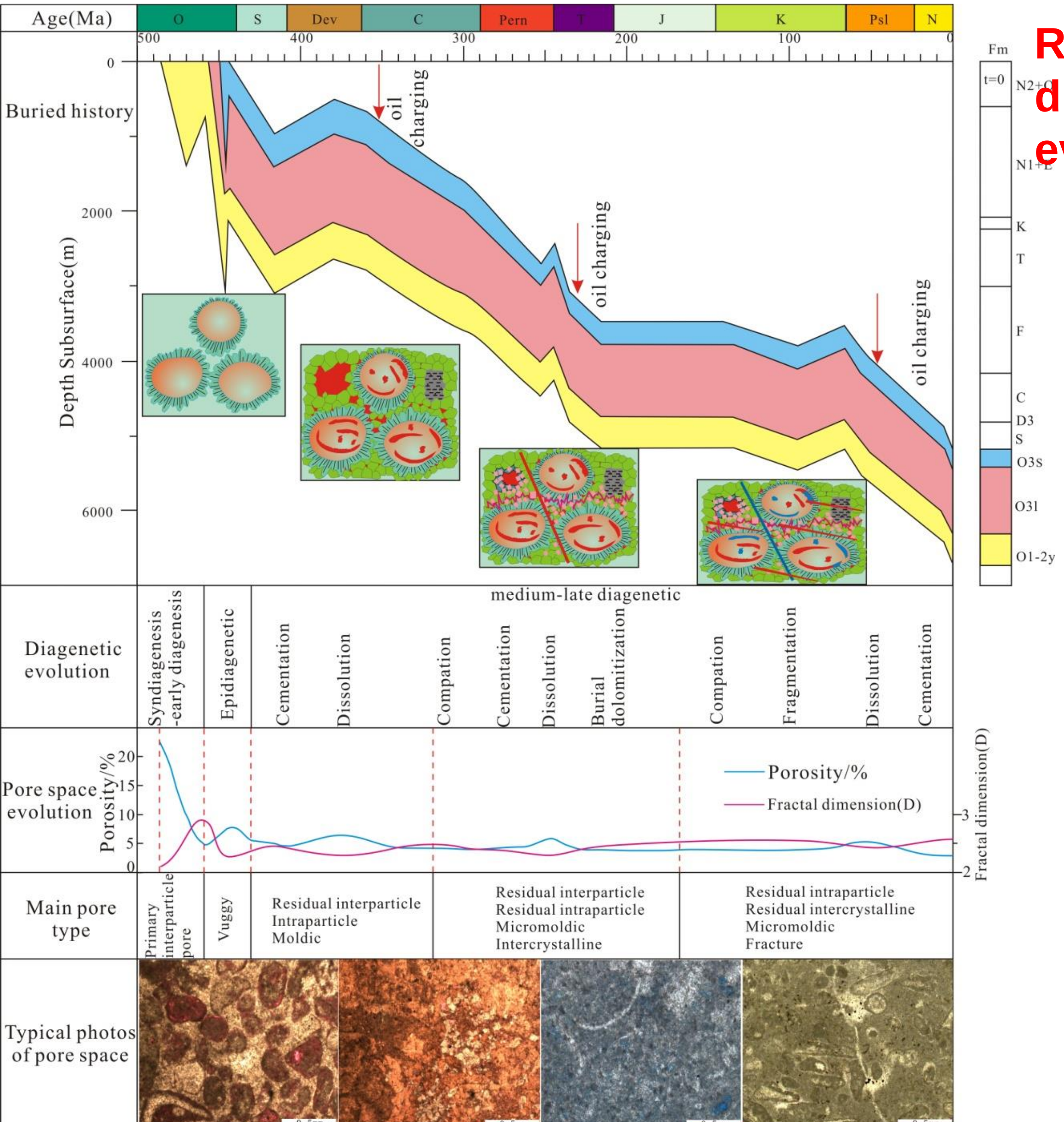
Porosity	34%	Porosity	34%
Number of pores	14	Number of pores	56
Number of throats	39	Number of throats	166
Dominant pore size	1500 μm	Dominant pore size	730 μm
Perimeter over area	3mm^{-1}	Perimeter over area	6.2mm^{-1}

➢Results and discussion



Pore geometric parametersand their relationships with fractal dimensions

➢Results and discussion



Relationships between fractal dimentions and diagenetic evolution

➢Conclusion

◆The FE-SEM mosaics reveal three main types of microporosity in the analyzed samples: **small intercrystalline pore** in the packstone and wackestone; **large intercrystalline pore** in dolomitic packstone; **moldic pore** in grainstone and dolomitic packstone.

◆ MICP data of carbonate plugs show these carbonate rocks have a relatively strong heterogeneity and complex pore structure.

◆Quantified pore geometric parameters (including the DOMsize, PoA, BTR and γ_a,) derived from DIA indicate pore morphology has a great influence on the pore structure and fluid flows behavior.

◆ The fractal dimension also reflects self-similarity of the pore space in the porous media. Crystalline growth process of carbonate rocks deposited in different sedimentary environment can influence a fractal pore structure. Furthermore, diagenesis is another important physical process that affects the original self-similarity of carbonates across all length scales.