Influences of TOC on Pore Structure of Shale from Montney Formation, West-Central Alberta, Canada

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Key words: Tight gas, TOC, pore structure, thermal evolution

Abstract: Shale gas has become one of the key points for the development of unconventional oil and gas. To better understand the influence factors of TOC in shale from Montney formation, total organic carbon (TOC), Rock-Eval analysis and saturation measurements were conducted to quantitatively analyze the influence factors of TOC. The results show that the kerogen type in the study block is gas-prone. Porosity and permeability have good correlations with TOC for high-maturity samples, demonstrating that organic pores are well developed in studied shale. The relationship between TOC and T_{max} is not obvious in low maturity samples, whereas the relationship between TOC and T_{max} show a negative correlation for the samples with high maturity. Organic matter begins to transform into hydrocarbon before T_{max} reaches a certain level. Gas saturation increases with the rise of TOC. Bulk density decreases with the increase of TOC. In general, TOC has a great influence on the pore structure of shale and the hydrocarbon-generating transformation of kerogen and could well characterize the gas content and thermal evolution of the reservoir.

1 INTRODUCTION

Shale gas is one of the most important types of unconventional oil and gas resources (Shao et al. 2017; Wei X et al. 2018; Sayed et al. 2017). Shale gas usually refers to natural gas with low economic value in low-permeability shale reservoir that have no natural capacity and can be produced through large-scale fracturing or special process technologies (Holditch, 2006; Ji et al. 2016). Shale reservoirs are mostly distributed in the center of the basin or deep in the basin structure, showing a large area of continuous distribution. Permeability, formation pressure, water saturation and porosity are the most important evaluation parameters for shale gas (Wang et al. 2012; Chukwuma et al. 2018; Zou et al. 2012).

In order to form a shale gas sweet spot, the effective source rock thickness should be greater than a certain value. TOC is also an important parameter for the evaluation of shale and the selection of sweet spots. The development of shale pores is closely related to the organic matter (Curtis et al. 2010). Organic matter forms nanoscale pores in the process of maturation and evolution (Slatt and O'Brien, 2011; Loucks et al. 2012). The higher the content of TOC, the larger the specific surface area of the core (Wang et al. 2015), indicating that organic carbon is an important factor in controlling the pore development of the reservoir. The effect of TOC on the pore structure in shale has been not fully studied (Milliken et al. 2013; Mastalerz et al. 2013).

The major goals of this article are to understand the physical properties, thermal evolution, fluid composition and bulk density of the shale through various experiments. The relationships between TOC and pore structures were discussed to understand the effect of TOC on pore structure. The relationships between TOC and T_{max}, gas saturation and bulk density were established to explore the influence factors of TOC. This study are of great importance for deepening the understanding of TOC in shale gas reservoirs.

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Table 1: Pore structure and Geochemical parameters of studied shale samples.

Samples	Depth	Porosity	Permeability	Bulk density	TOC	Tmax	Production	Gas Saturation
	m	%	mD	g/cc	%	°C	Index	%
1	2139.10	11.32	0.001770	2.62	1.07	370	0.32	0.71
2	2142.00	9.13	0.001060	2.60	1.55	317	0.62	1.54
3	2147.10	6.80	0.000066	2.55	3.25	342	0.58	1.59
4	2148.60	5.67	0.000018	2.60	4.43	351	0.73	2.02
5	2151.00	3.30	0.000012	2.53	3.89	491	0.48	2.14
6	2152.00	2.77	0.000006	2.55	3.57	489	0.42	1.35
7	2154.00	3.21	0.000009	2.56	3.52	490	0.33	1.77
8	2155.80	2.44	0.000008	2.54	3.80	496	0.32	1.48
9	2157.10	3.20	0.000008	2.53	3.03	486	0.49	2.21
10	2157.80	5.09	0.000011	2.52	3.04	319	0.64	3.40
11	2161.80	3.28	0.000027	2.51	5.87	496	0.41	1.99
12	2162.70	2.17	0.000012	2.58	3.18	516	0.61	1.11
13	2165.40	1.45	0.000006	2.64	1.70	506	0.58	0.55
14	2166.60	2.34	0.000007	2.56	5.07	502	0.47	1.03
15	2167.20	3.02	0.000012	2.43	4.35	529	0.65	1.74
16	2168.80	2.45	0.000010	2.71	0.67	370	0.84	0.52
17	2172.10	1.18	0.000001	2.76	0.50	326	0.92	0.39
18	2176.50	2.14	0.000036	2.74	0.90	427	0.66	0.52
19	2182.80	1.81	0.000003	2.75	1.00	571	0.77	0.25
20	2186.60	1.41	0.000006	2.73	1.55	311	0.89	0.26

2 SAMPLES AND METHODS

The Montney Formation is a late Triassic mainly fine-grained unit, deposited in marine environments, with a large-scale distribution of the reservoir bodies. The unit is up to 280 meters thick and the facies are shaley in the north and west areas, silty in the center and become coarser (sandy) in western Alberta. The brittle quartzic content is about 40%, making it is easy to improve the physical properties of the reservoir through fracturing.

Routine experiments were performed on 20 samples from Montney formation, west-central Alberta, Canada. Retort saturation measurements were performed on core samples. Porosity, grain density and fluid saturation were calculated from a representative portion of the crushed sample and the whole sample was used for bulk density determination. Rock Eval analysis is a standardized method for describing the thermal maturities, types and hydrocarbon generation potential of organic matter in sedimentary rocks. Saturation measurements with retort method were conducted on samples. The parameters obtained in this study are listed in Table 1.

3 RESULTS AND DISCUSSION

3.1 Effect of TOC on Pore Structure Parameters

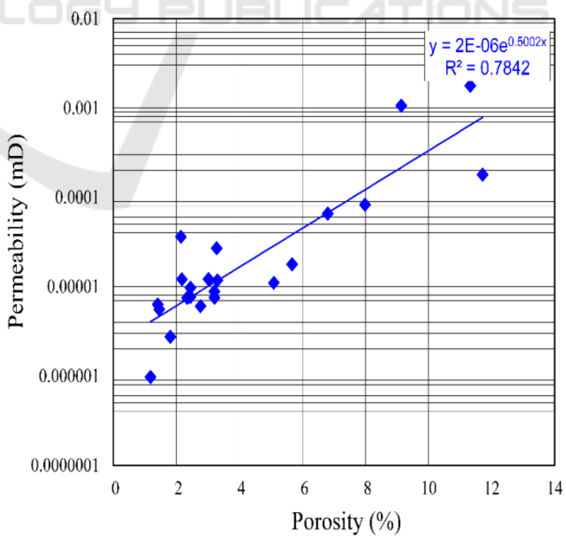

Figure 1: Relationship between porosity and permeability.

The permeability ranges from 0.000001 mD to 0.001770mD, with an average value of 0.000152 mD. The porosity ranges from 1.2 % to 11.7 %, with an average value of 4.3%. This shale gas reservoir can be characterized as low porosity, low permeability and shows strong heterogeneity. The porosity shows a good exponential relation with the permeability (Figure 1), with the correlation coefficient of 0.7842.

The relationship between TOC and organic pores has been widely studied (Curtis et al. 2012; Chen and Xiao, 2014), and the effect of TOC on porosity was not fully studied. The number of organic pores generally increases with the rise of TOC, whereas the relationship between TOC and porosity varies in different sedimentary reservoir (Milliken et al. 2013; Mathia et al. 2016). Lai found that the pore space is mainly composed of intergranular pores, intragranular pores and microfractures in shale from Kelasu thrust belt (Lai and Wang, 2015). Organic nanopores and microfractures formed by the migration of fluid in kerogen are related to the development of TOC. Figure 2 depicts the relationship between TOC and porosity. For the samples with low maturity, the relationship between TOC and porosity is not obvious, whereas the relationship between TOC and porosity have a good positive correlation for the samples with high maturity. The result demonstrates that the difference exists in pore types between low-maturity and high-maturity samples. Organic pores or microfractures formed by the migration of fluid in kerogen developed in high-maturity samples, whereas organic pores are not well developed in low-maturity samples. Permeability has the similar law as porosity, as shown in Figure 3. In general, pore types and their distribution determine the relationships between TOC and pore structure parameters.

3.2 Relation between TOC and Maturity

Maturity of organic matter not only reflects the conversion of organic matter into oil and gas, but also characterizes the development of pores in the reservoir (Chen and Xiao, 2014). The relationship between maturity of organic matter and pore structure is complex because thermal evolution will not only cause changes in the porosity of organic matter, but also cause the conversion of clay minerals (Chen and Xiao, 2014).The relationship between TOC and organic pores and the relationship between the maturities of thermal evolution have been widely discussed. However, the relationship between the maturity of thermal evolution and TOC was rarely studied. T_{max} is an important parameter to evaluate the maturity of organic matter. Organic matter begins to transform into hydrocarbon before T_{max} reaches a certain level. The kerogen of samples in this study is in a high-mature stage and achieves high level conversion when T_{max} is greater than 450℃ (Figure 4). Figure 4 also shows that the kerogen type in the study block is gas-prone.

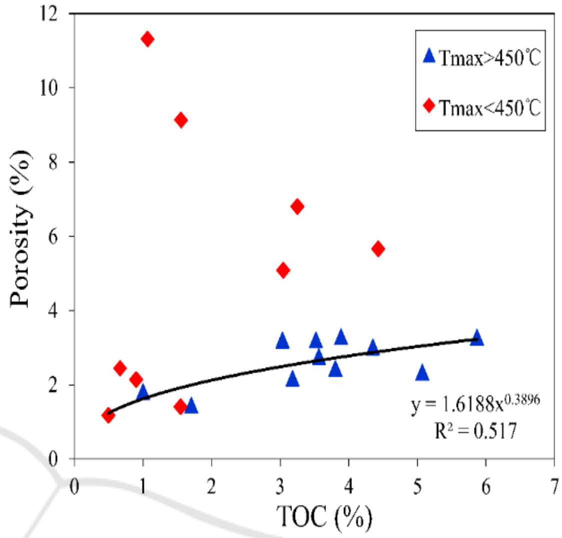

Figure 2: Relationship between TOC and porosity.

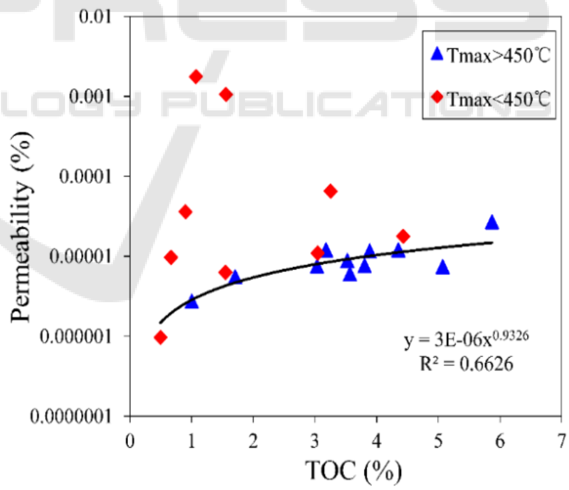

Figure 3: Relationship between TOC and permeability.

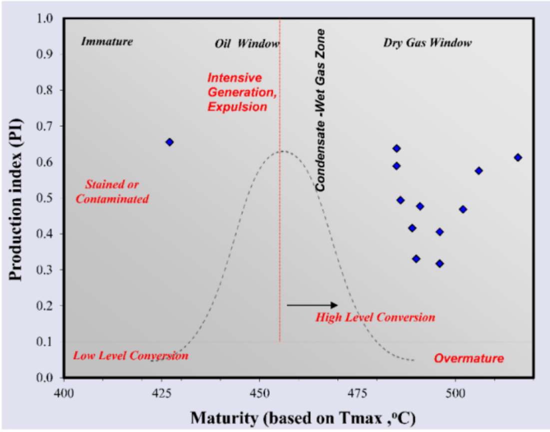

Figure 4: The determination of kerogen type based on the correlation between T_{max} and PI.

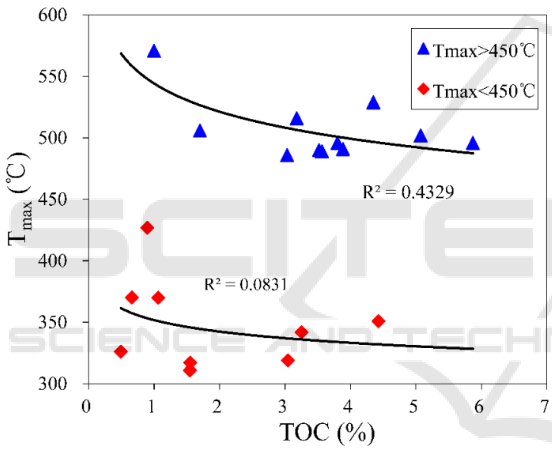

Figure 5: Relationship between TOC and T_{max}.

Figure 5 shows that for the samples with low maturity, the relationship between TOC and T_{max} is not obvious, whereas the relationship between TOC and T_{max} show a weak negative correlation for the samples with high maturity. Along with the enhancement of thermal evolution, organic matter generates hydrocarbons and forms pores, thus the amount of organic matter decreases, which is the reason for the decrease of TOC with the rise of T_{max} in mature stage. The hydrocarbon generation of kerogen is related to various factors, such as mineral composition, kerogen type and compaction (Curtis et al. 2012). In the immature stage, organic matter is not converted to hydrocarbon. The abundance of organic matter is mainly related to the depositional conditions of the reservoir in the low maturity stage, which is the reason for the weak correlation between TOC and T_{max}. Therefore, no obvious correlation exists between TOC and T_{max} in immature stage.

3.3 Relation between TOC and Gas Saturation

The above discussion shows that organic matter begins to transform into hydrocarbon before T_{max} reaches a certain level. In this study, the T_{max} of some samples is less than 400, and is in the immature stage. Figure 6 shows that all samples have gas saturation. The gas in immature samples may be transported from the mature samples, which already have more organic matter transformation. Perhaps because the kerogen type in the study block is gas-prone and begins to transport into gas at lower degrees of thermal evolution, which could be demonstrated by Figure 6. In general, for high-maturity samples, the gas saturation increases with the rise of TOC and the enhancement of thermal evolution. The obvious correlation between TOC and gas saturation was not depicted in Figure 6 for low-maturity samples. This further confirms that the gas in the low-maturity samples was migrated from the nearby high-maturity samples.

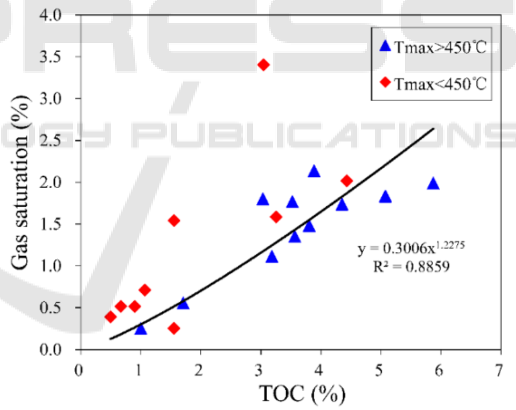

Figure 6: Relationship between TOC and gas saturation.

3.4 Relation between TOC and Density

Milliken found that when the TOC is less than 5.6%, the porosity shows an increase with increasing TOC content, while there is a certain negative correlation between porosity and TOC when the TOC is greater than 5.6% (Milliken et al. 2013). The inhibitory effect of high TOC content on organic pores may be due to mechanical compaction or microcomponents of non-hydrocarbon generation contained in organic matter. The high TOC reservoirs have stronger ductile characteristics and are more susceptible to compaction under formation conditions. Figure 7 shows that bulk density decreases with the rise of TOC, indicating that the higher the organic matter content, the smaller the density of the reservoir. Higher organic matter content means greater effect of the compaction on the reservoir, but high organic matter generally predicts a decrease in density.

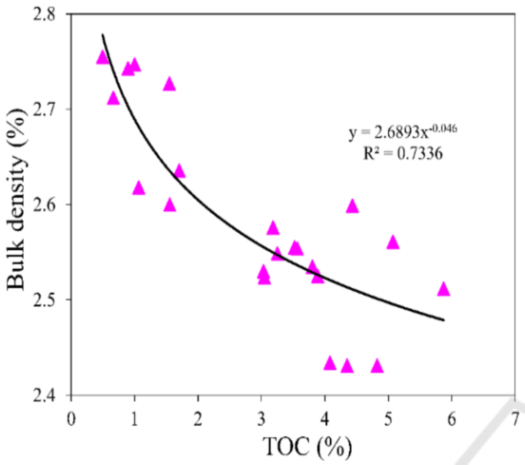

Figure 7: Relationship between TOC and bulk density.

4 CONCLUSIONS

In this paper, 20 samples in shale from Montney formation, west-central Alberta, Canada were subjected to various experiments to understand the effect of TOC on pore structure and the influence factors of TOC. The following conclusions have been obtained.

- The reservoir in this study is characterized by low porosity, low permeability and shows strong heterogeneity. For high-maturity samples, TOC has a good positive correlation with porosity and permeability.
- The TOC is affected by thermal evolution, organic hydrocarbon generation and mineral composition. When T_{max} is greater than a certain level, thermal evolution will have an impact on TOC.
- The gas in the low-maturity samples was migrated from the nearby high-maturity samples. The gas saturation increases with the rise of TOC and the enhancement of thermal evolution for high-maturity samples.
- Bulk density decreases with the rise of TOC, indicating that the higher the organic matter content, the smaller the density of the reservoir.

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