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Prediction Models of Organic Pores in Shale

Focus on Lacustrine Shale During Low to Moderate Maturity in China

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Outline

- Introduction
- Prediction models of organic pores in shale
- Comparison of calculation results
- Conclusions

Introduction

In recent years, the research of shale organic matter porosity focused on shale in the high-over maturity stage. The main research purpose was to serve the shale gas E&D.

The quantitative prediction of the organic matter porosity of shale during low to moderate maturity is of great significance to the evaluation of shale oil resources.

Prediction models of organic pores in shale

1. Theoretical models

- **Transformation ratio (*Tr*) model**
- **Hydrocarbon generation rate (*Gr*) model**

2. Statistical models

- **Lacustrine shale in China**
- **Marine shale in North America**

1. Theoretical models

(1) Transformation ratio (*Tr*) model

The transformation rate model refers to the calculation method of organic matter porosity based on the evolution of organic matter maturity and the hydrocarbon generation process.

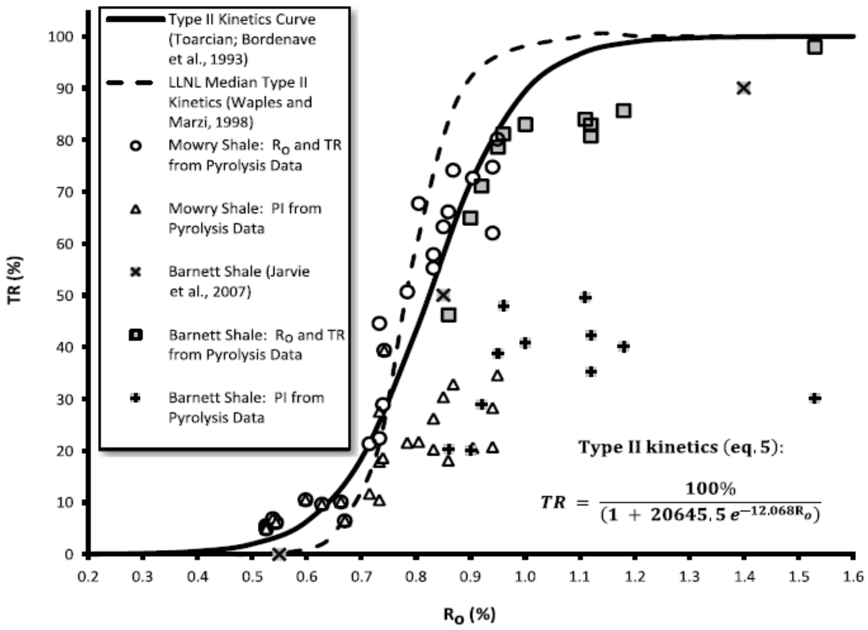
$$p_{om} = iTOC \times Cc \times k \times Tr \times (\rho_{rock} / \rho_{TOC}) \times 10^{-4} \quad (1)$$

where, p_{om} – the organic matter porosity, %;
$iTOC$ – the weight percentage of initial total organic carbon, %;
Cc – the percentage of convertible carbon, %;
k – the conversion factor, 1.18;
Tr – the transformation rate, namely, the percentage of organic carbon converted to hydrocarbons, %;
ρ_{rock}, ρ_{TOC} – the rock density and the organic carbon density, respectively, g/cm^3.

1. Theoretical models

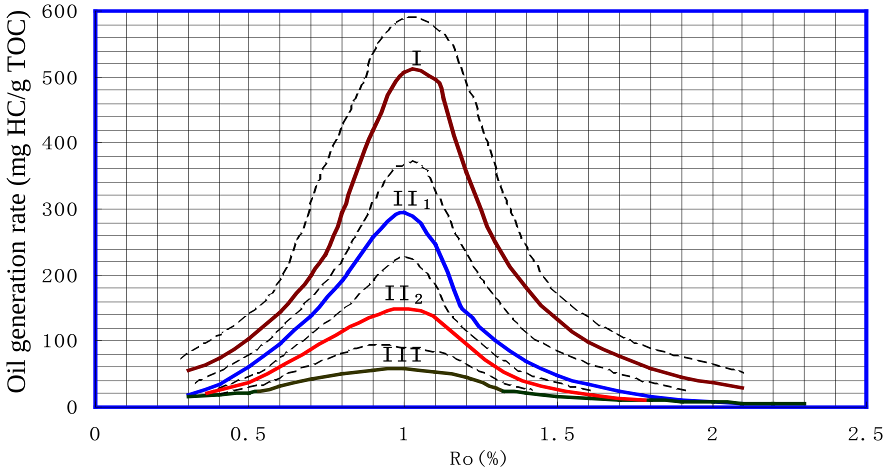
(2) Hydrocarbon generation rate (*Gr*) model

Type II kerogens（Modeica， 2012）



Transformation rate to *Ro* relation

The hydrocarbon generation rate, different from the transformation rate, is the ratio of hydrocarbons generated by the initial total organic carbon.



Oil generation rate to *Ro* relation

1. Theoretical models

(2) Hydrocarbon generation rate (*Gr*) model

According to the law of conservation of matter, when the initial organic carbon per gram generates W_{hc} mg of hydrocarbon, the weight of organic matter consumed is:

$$m_1 = \frac{W_{hc}}{1000 \times k} \qquad (2)$$

In the shale with the initial organic carbon content of ***iTOC***, the weight of the organic matter consumed per gram of rock is:

$$m_2 = m_1 \times iTOC \qquad (3)$$

(2) Hydrocarbon generation rate (*Gr*) model

The percentage of the volume of organic matter consumed by per gram of rock in the rock volume is calculated by:

$$p_{om} = (m_2 / \rho_{TOC}) / (1 / \rho_{rock}) = m_2(\rho_{rock} / \rho_{TOC}) \qquad (4)$$

Substituting Formula (2) into Formula (3), and then substituting Formula (3) into Formula (4), we can obtain:

$$p_{om} = \frac{W_{hc}}{k \times 1000} \times iTOC \times (\rho_{rock} / \rho_{TOC}) \qquad (5)$$

In Formula (5), W_{hc} means the hydrocarbon generation rate, mg HC/g TOC

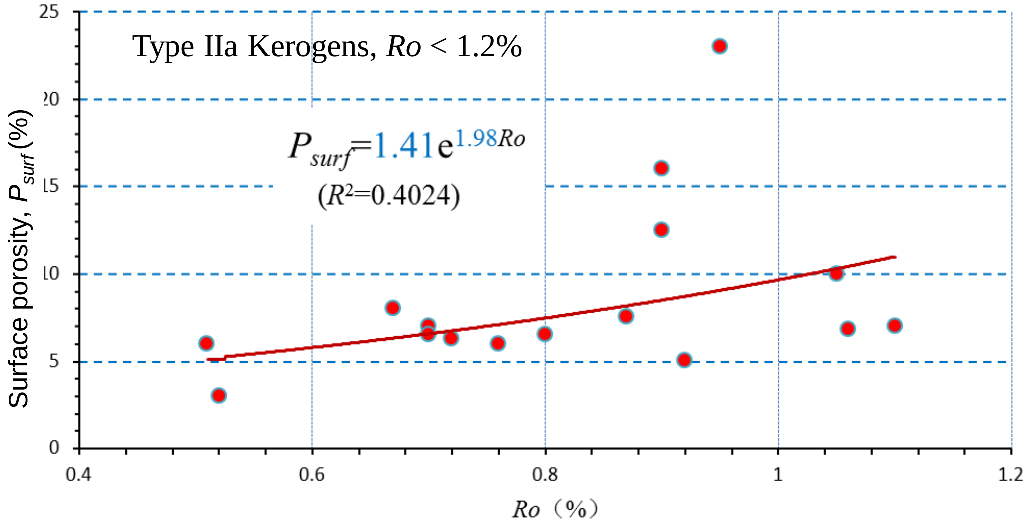
(2) Hydrocarbon generation rate (*Gr*) model

Results of the Gr model and Tr model

Ro/%	*Tr*/%	W_{hc}/mg HC/g TOC	*iTOC*/wt%	HI_o/mg HC/g TOC	*Cc*/%	*Gr* model P_{om}/%	*Tr* model P_{om}/%
0.2	0.05	0	6	430	36.55	0.00	0.00
0.4	0.60	3	6	430	36.55	0.03	0.03
0.5	1.98	20	6	430	36.55	0.22	0.11
0.55	3.56	25	6	430	36.55	0.28	0.20
0.63	8.85	50	6	430	36.55	0.55	0.50
0.7	18.43	100	6	430	36.55	1.10	1.03
0.8	43.02	210	6	430	36.55	2.31	2.41
0.9	71.63	350	6	430	36.55	3.86	4.02
1	89.40	385	6	430	36.55	4.24	5.01
1.1	96.58	420	6	430	36.55	4.63	5.41

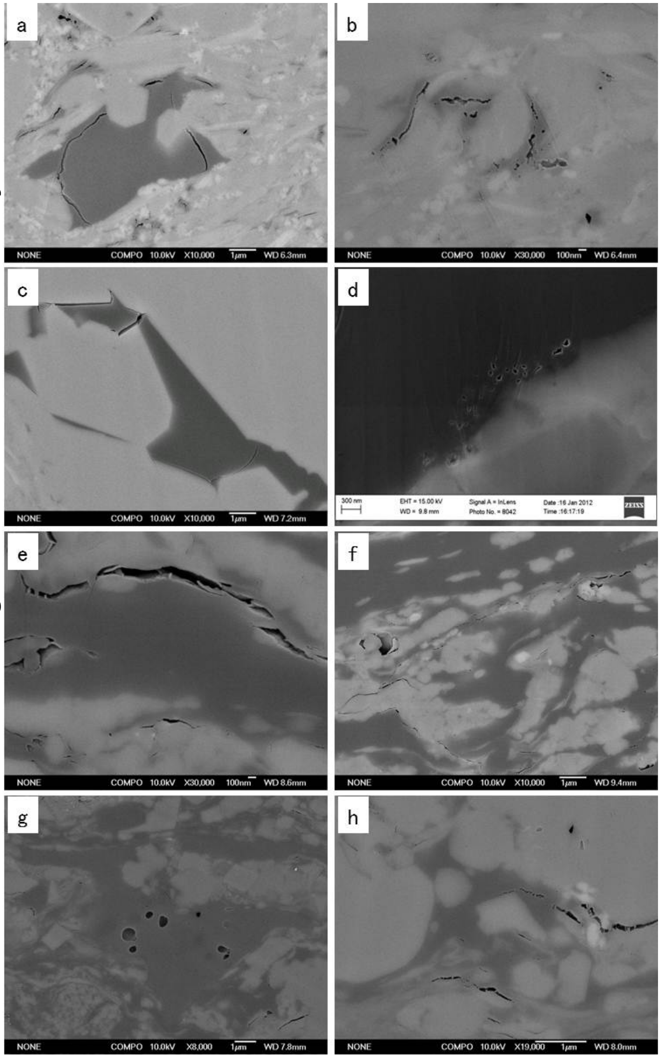
2. Statistical models

The model for the relationship between p_{surf} and *Ro* of shale during low to moderate maturity in China



The surface porosity has an exponential relationship with Ro, and it increases slowly at the stages of low to moderate maturity.

Lacustrine shales during low to moderate maturity in China



2. Statistical models

The model for the relationship between p_{surf} and Ro of shale during low to moderate maturity in China

$$p_{om} = \frac{p_{surf}}{100} \times TOC \times (\rho_{rock} / \rho_{TOC}) \quad (6)$$

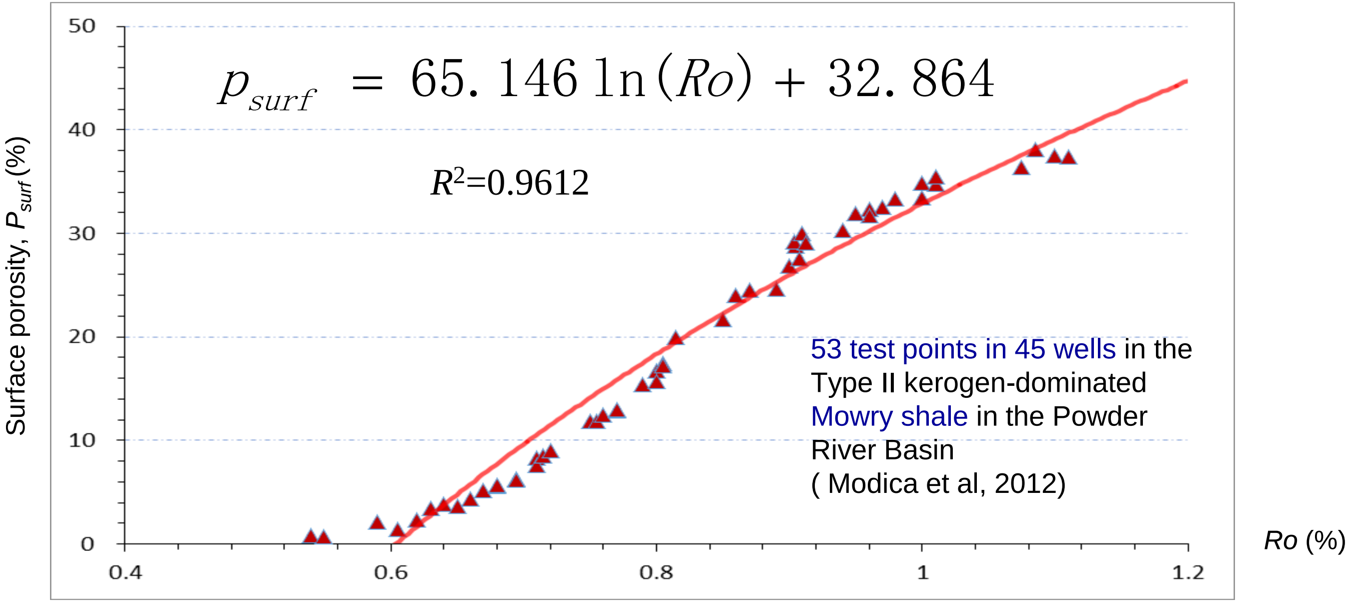
$$\begin{cases} p_{surf} = 0 & Ro < 0.4 \\ p_{surf} = ae^{bRo} & Ro \geq 0.4, Ro \leq 1.3 \end{cases} \quad (7)$$

where, p_{surf} – the surface porosity of organic matter, %;
TOC – the percentage of the weight of organic carbon to the total weight of shale, %;
Ro – the maturity of organic matter, %;
a, *b* – the regression coefficient, which is related to the type of organic matter. Taking Type IIa kerogen as an example, *a* is 1.41 and b is 1.98.
Other symbols are the same as Formula (1).

The surface porosity has an exponential relationship with Ro, and it increases slowly at the stages of low to moderate maturity.

2. Statistical models

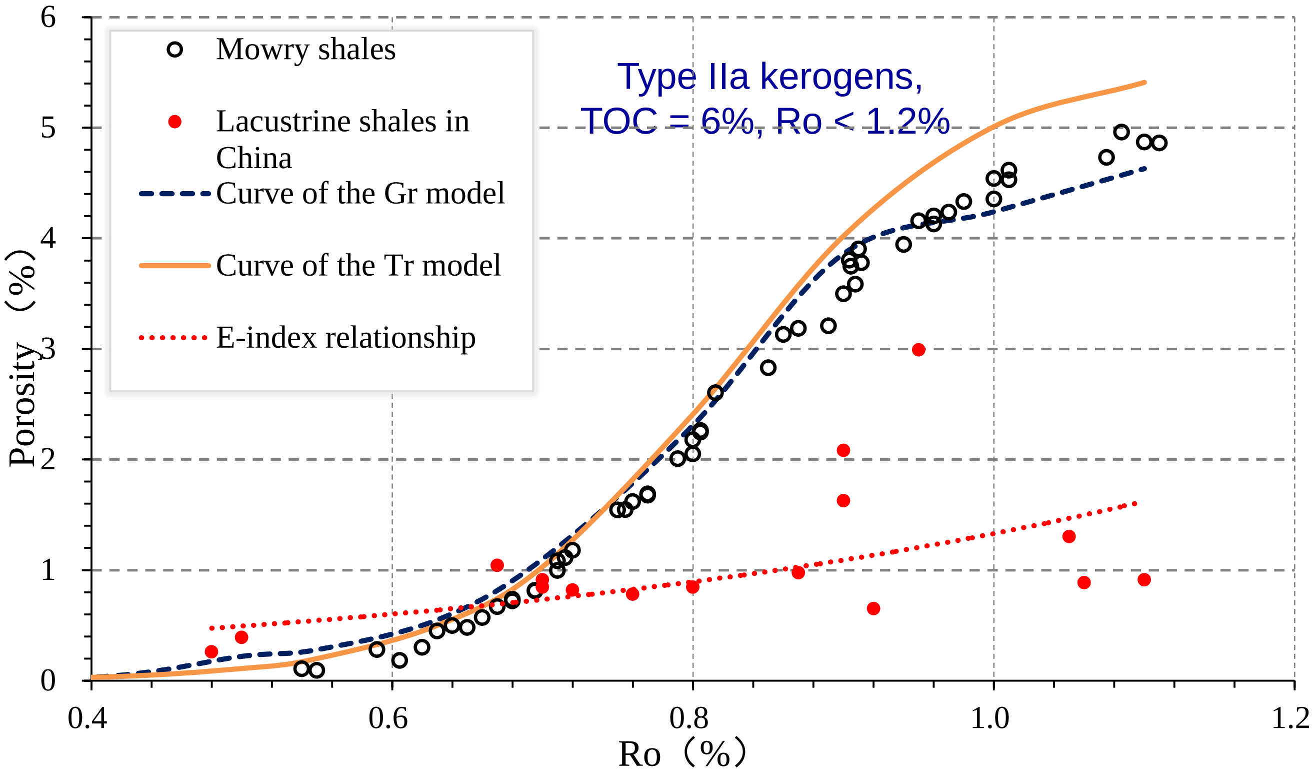
The model for the relationship between p_{surf} and *Ro* of shale during low to moderate maturity in North America



The surface porosity has an logarithmic relationship with Ro, and it increases rapidly at the stages of low to moderate maturity.

Comparison of calculation results

1. Calculation results



In the figure, TOC is taken as 6%. During the practical application, if the actual TOC is 1%, the organic matter porosity is 1/6 as shown in the figure; if the actual TOC is 12%, the organic matter porosity is twice as that shown in the figure

Comparison of calculation results

2. Applicability

- For the **marine shale in North America, both the theoretical model and the statistical model are suitable.** There is a logarithmic relationship between the surface porosity and *Ro*, which means that **during low to moderate maturity, the surface porosity growth is faster.**

- For the **lacustrine shale during low to moderate maturity in China, the theoretical model is not suitable,** but the statistical model is suitable. There is an E-index relationship between the surface porosity and *Ro*, that is, **during low to moderate maturity, the surface porosity growth is slower.**

Comparison of calculation results

3. Discussion

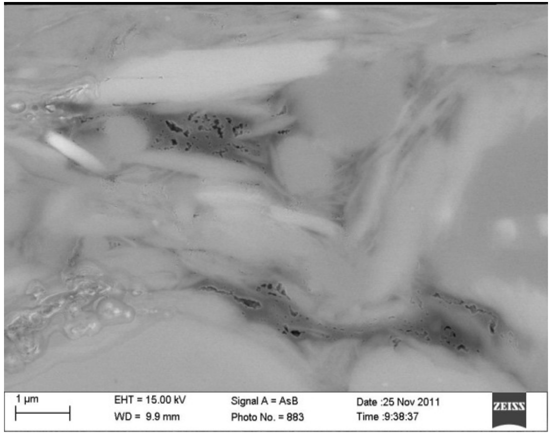
■ **The difference between theoretical model and statistical model**

- The result of **the theoretical model** represents the upper limit of the organic matter porosity, which is the maximum porosity of organic matter undamaged.
- The result of **the statistical model** is close to the actual observations, which is the actual porosity of organic matter with the impact of various geological effects, including compaction, diagenesis and solid asphalt filling.

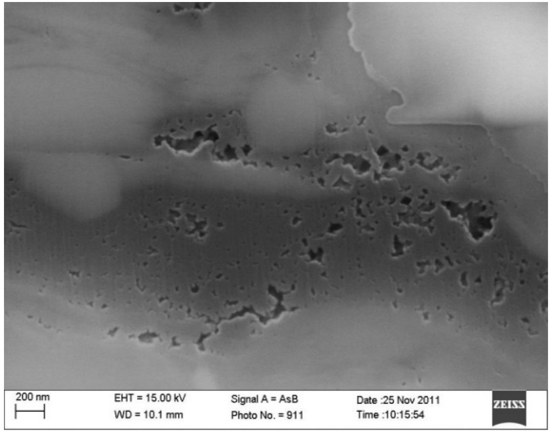
3. Discussion

- **The difference between the oil window stage (moderate - low maturity) and the gas generation stage (high-over maturity)**

High-over Maturity (Ro > 2.4%)

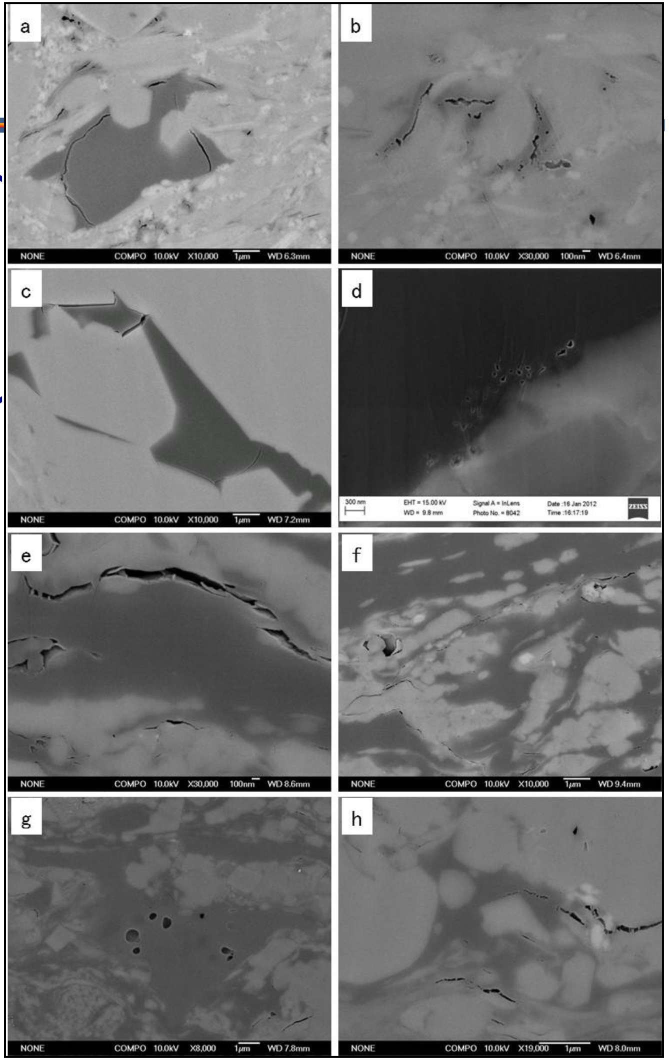


FA-6: *Ro*: 2.41%, TOC: 2.1%



FA-8: *Ro*: 2.42%, TOC: 2.5%

Lacustrine shales in China (Ro < 1.0%)



3. Discussion

The difference between lacustrine shale in China and marine shale in North America

- **The main difference is reflected in the shale during low to moderate maturity.**
  - The major oil-producing shales in China all **belong to lacustrine shale** in the middle-low maturity stage.
  - The typical shale in North America **belong to marine shale,** with plenty of organic matter pores during low to moderate maturity.
- **The heterogeneity of Type II kerogen of lacustrine shale is stronger than that of marine shale.**

Conclusions

1. According to the law of conservation of matter, Tr Model and Gr Model are established. Both models can predict the upper limit of the theoretical organic matter porosity of shale and have a reference value for the evaluation of shale oil resources.

2. Based on the observation of samples and statistical results, the relationship between the surface porosity and Ro is established. The findings are obtained in two aspects. First, there is an E-index relationship between the surface porosity of organic matter and *Ro* for the lacustrine shale in China. Second, there is a logarithmic relationship for the marine shale in North America.

3. For the lacustrine shales during low to moderate maturity in China, the theoretical model is not suitable, but the statistical model is suitable. For the marine shale in North America, both the theoretical model and the statistical model are suitable.

Thank You / Questions

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