Forward Analysis of the Sources and Relative Contributions of Marine Oil and Gas in the Tarim Basin*

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Search and Discovery Article #10923 (2017)**
Posted March 13, 2017

*Adapted from oral presentation given at AAPG International Conference & Exhibition, Barcelona Spain, 2016

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Abstract

In recent years, more and more marine oil and gas have been found in the Tarim Basin. Due to the blend of multi-source oil and gas as well as multi-period tectonics in this superimposed basin, the origin and relative contribution of these marine oil and gas are not clear. The method of oil and gas-source correlation has been used to study this problem, however, the fact that the distribution of source rocks is quite different from the discovered oil and gas reflects its limitation. For this study, forward modeling method was used to simulate the processes of hydrocarbon generation and expulsion from source rocks in the Tazhong area of the Tarim Basin.

The amount of resources can be obtained by deducting the critical saturation of residual hydrocarbon, loss of diffusion phases, loss of hydrocarbon residue in the migration, and that damaged by tectonic movements, from the total amount of hydrocarbon expulsion. In these processes, the values of relative contribution of oil and gas in each accumulation period can also be calculated, which reflects the direct and indirect contributions of source rocks to the petroleum accumulation. From this study, different accumulation periods, different abundance of organic matter, different buried depth, different set of source rocks can all make differences on contributions to the oil and gas accumulations in the Tazhong area. Firstly, marine oil and gas is mainly from source rocks in the Cambrian and Ordovician, the amount of accumulated resources formed by the Cambrian source rock is about 2.9 billion tons, 63.2% of the total resources. Secondly, both high (TOC > 0.5%) and low (TOC < 0.5%) abundance of organic matter existed in the Cambrian and Ordovician source rocks. The amount of accumulated resources formed by source rocks with low abundance is about 2.0 billion tons, 32.6% of the total resources. In the multi-source oil and gas in the Tazhong area, the Cambrian source rocks may be dominant, in addition, low abundance source rocks have a certain contribution to the total resources and is worth attention in the future.

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ICE Barcelona
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Forward analysis of the sources and relative contributions of marine oil and gas in the Tarim Basin

Reporter: Qianwen Li

China University of Petroleum - Beijing

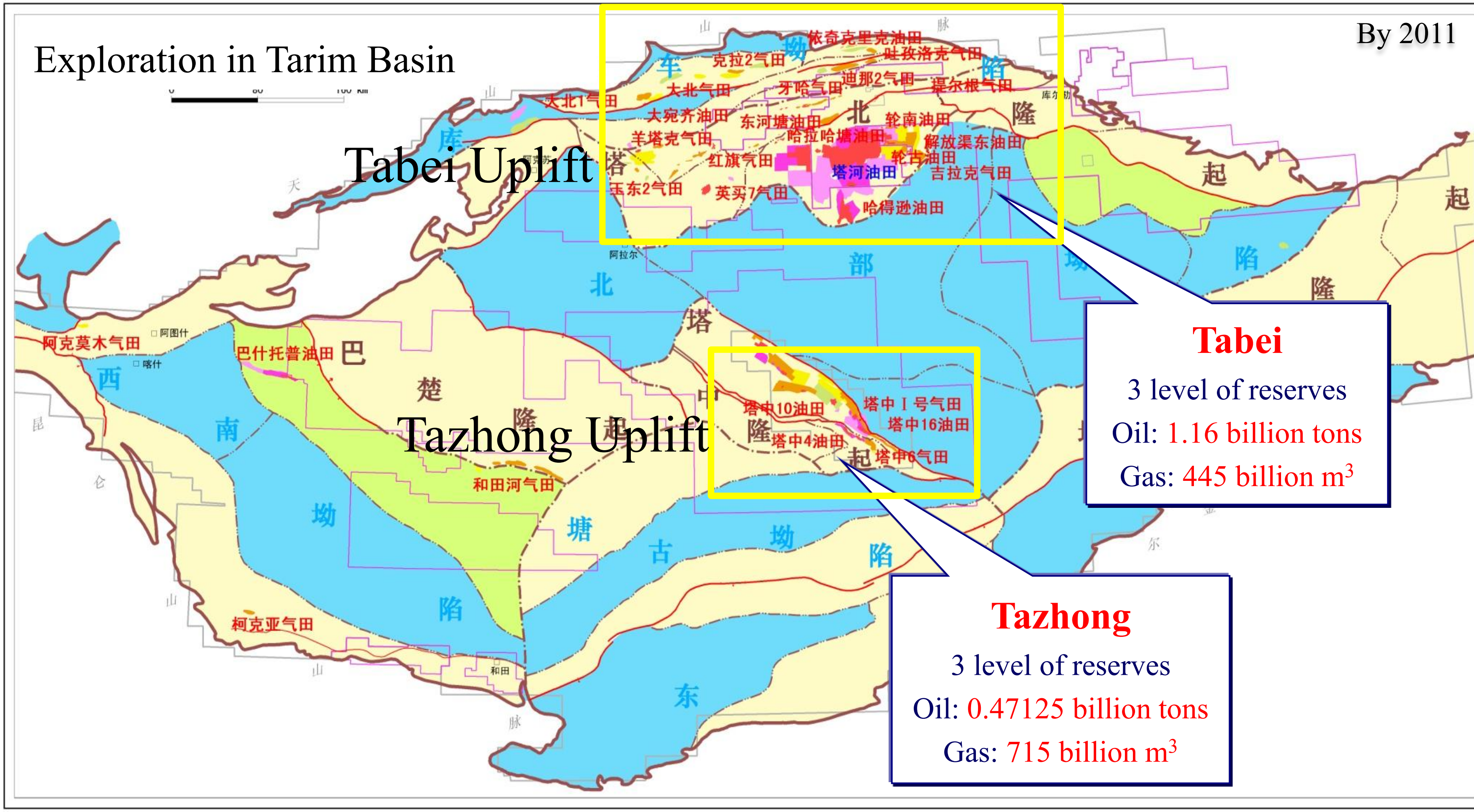
4/6/2016

Outline

1. Introduction
2. Geological background
3. Methods
4. Results
5. Discussion

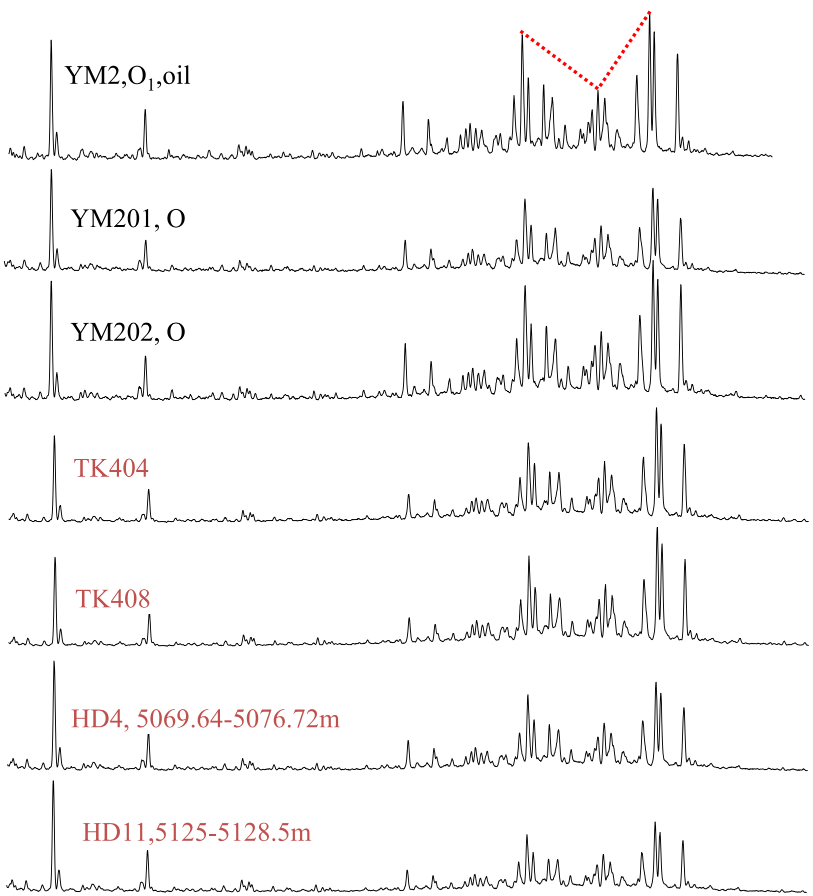
1. Introduction

Distribution of oil&gas in Tarim Basin

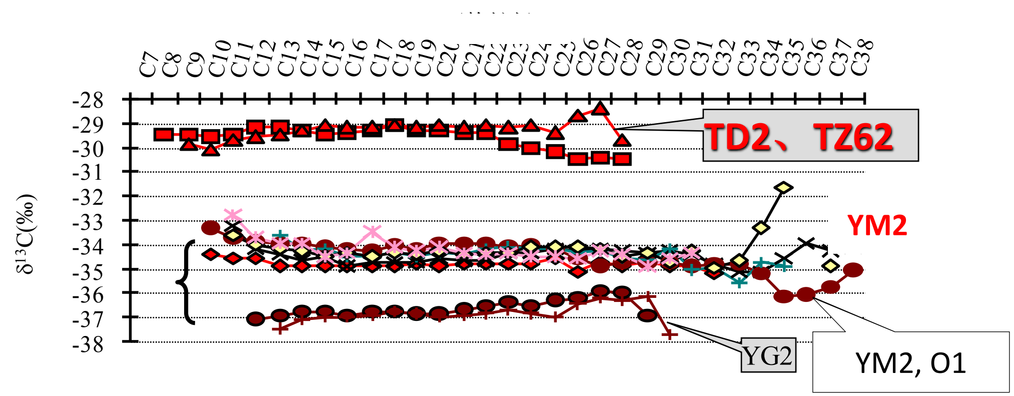


- Proved oil&gas fields: 29; proved reserves: oil 0.863 billion tons; gas 1280 billion m^3; oil equivalent 1.88 billion tons.
- Two main sets of source rocks: ∈-O_1 and O_{2+3}.

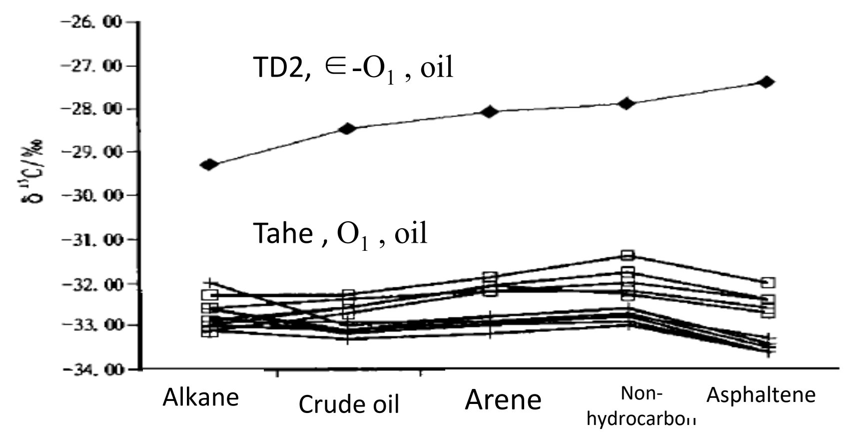
- **Geochemical analysis shows that these oil&gas mainly come from O_{2+3} source rock ---the same features of carbon isotope and biomarker in oil&gas and source rocks**



Biomarkers show the source of O_{2+3} in well YM2 (Li et al, 2012)



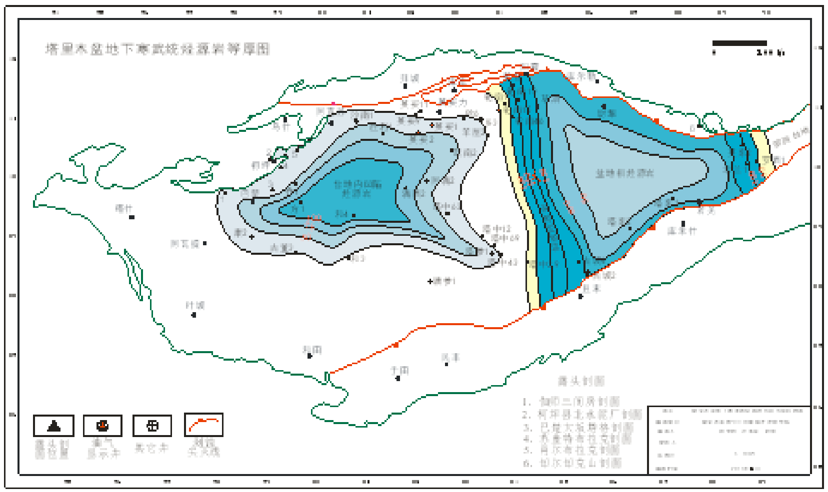
Source analyses with monomer hydrocarbon carbon isotope (Li et al, 2014)



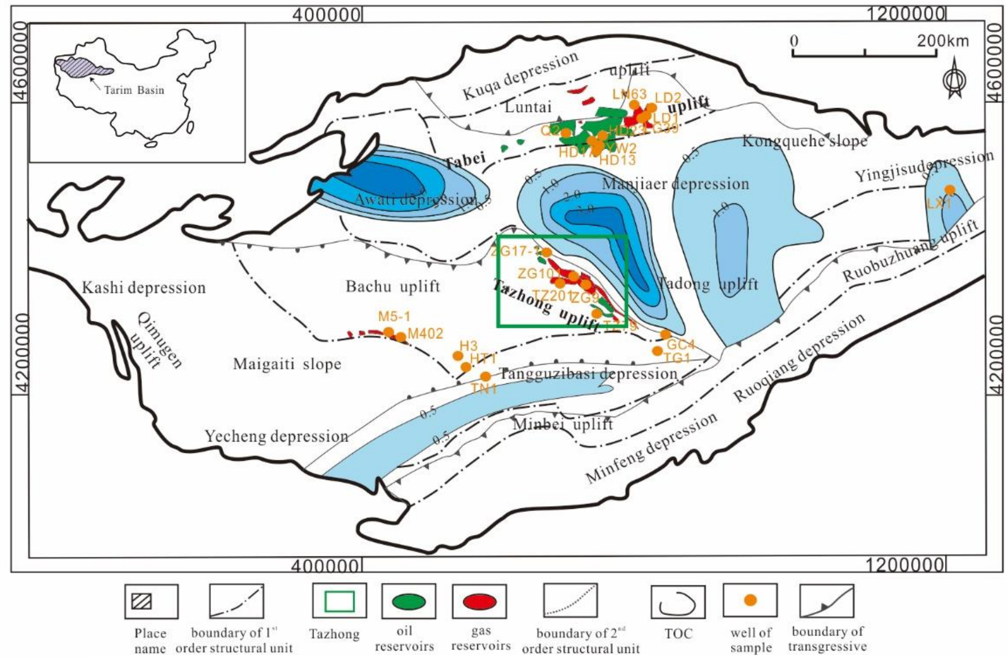
Distribution of carbon isotopic compositions of the Ordovician crude oil in Tahe Oilfield (Wang et al, 2004)

1. Introduction

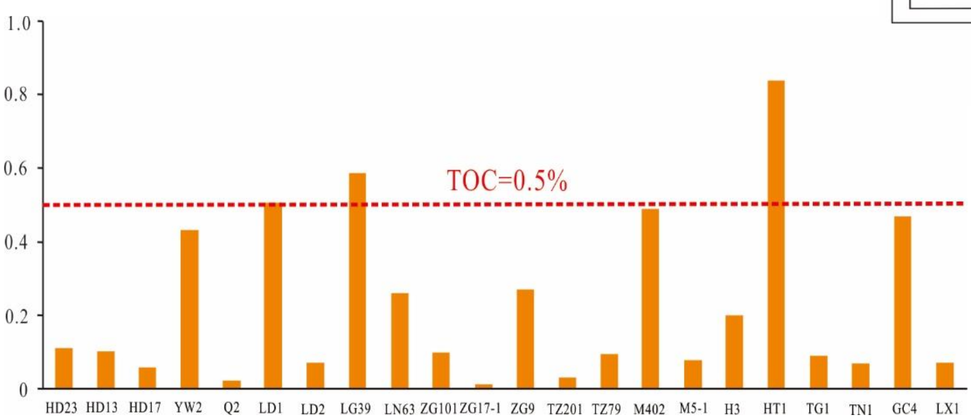
- **Geologic analysis shows that these oil&gas mainly come from $\in$-O_1 source rock --- O_{2+3} source rocks has characteristics of limited distributions and low content of TOC (mainly<0.5%)，however，the proved 3 level of reserves are large.**



Thickness distributions of $\in$-O_1 source rocks



TOC contour map of O_{2+3} source rocks



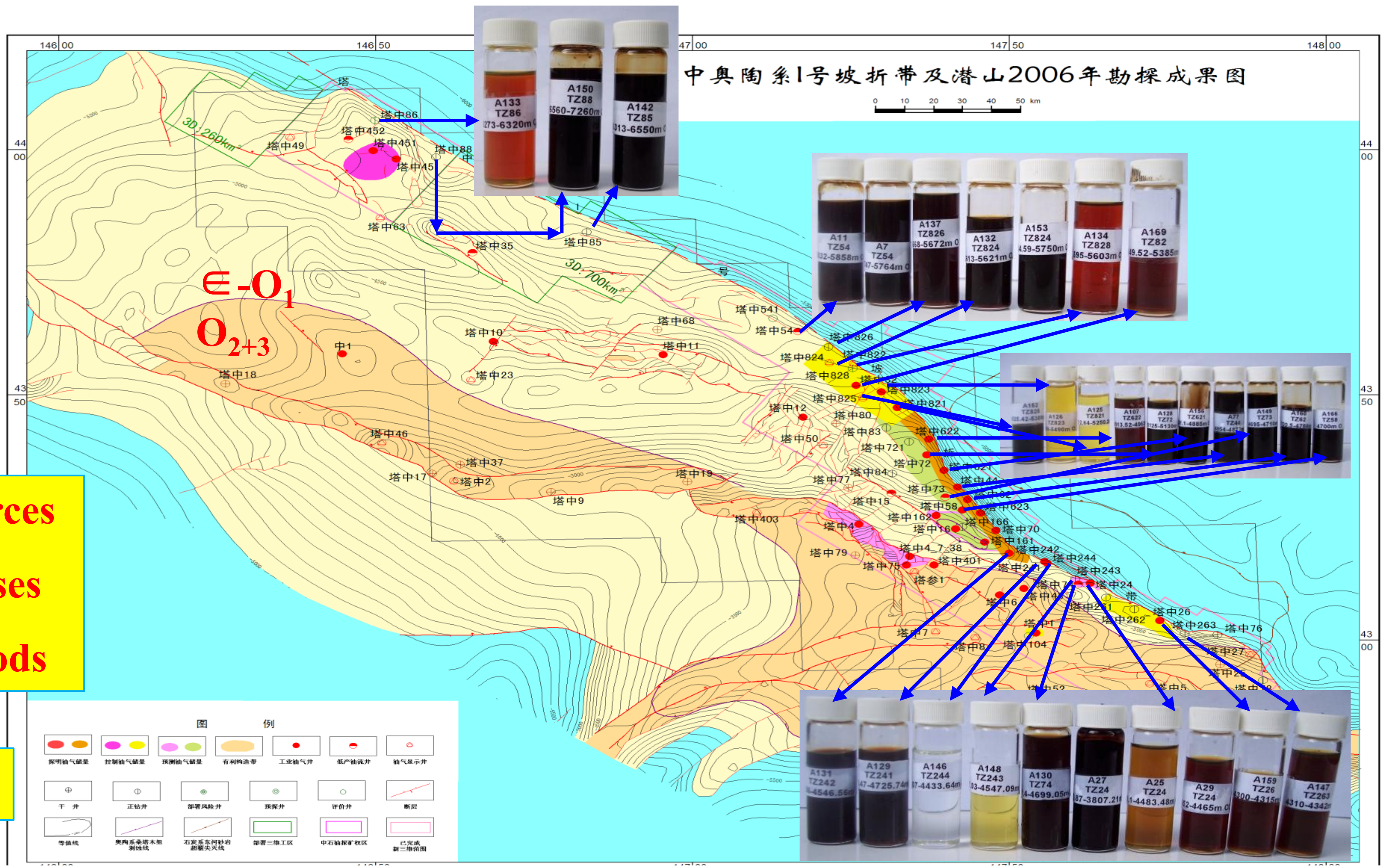
The distribution of TOC in the O2+3 source rock

The Third Resource Assessment of Tazhong:
oil 0.95 billion tons, gas 473 billion m^3

The three level of reserves of Tazhong:
total 1.041 billion tons, gas 594 billion m^3

1. Introduction

➢ Relative contributions of ∈-O_1 and O_{2+3} as well as source rocks with TOC>0.5% and TOC≤0.5%



Multi-Sources

Multi-Phases

Multi-periods

Mixing

Outline

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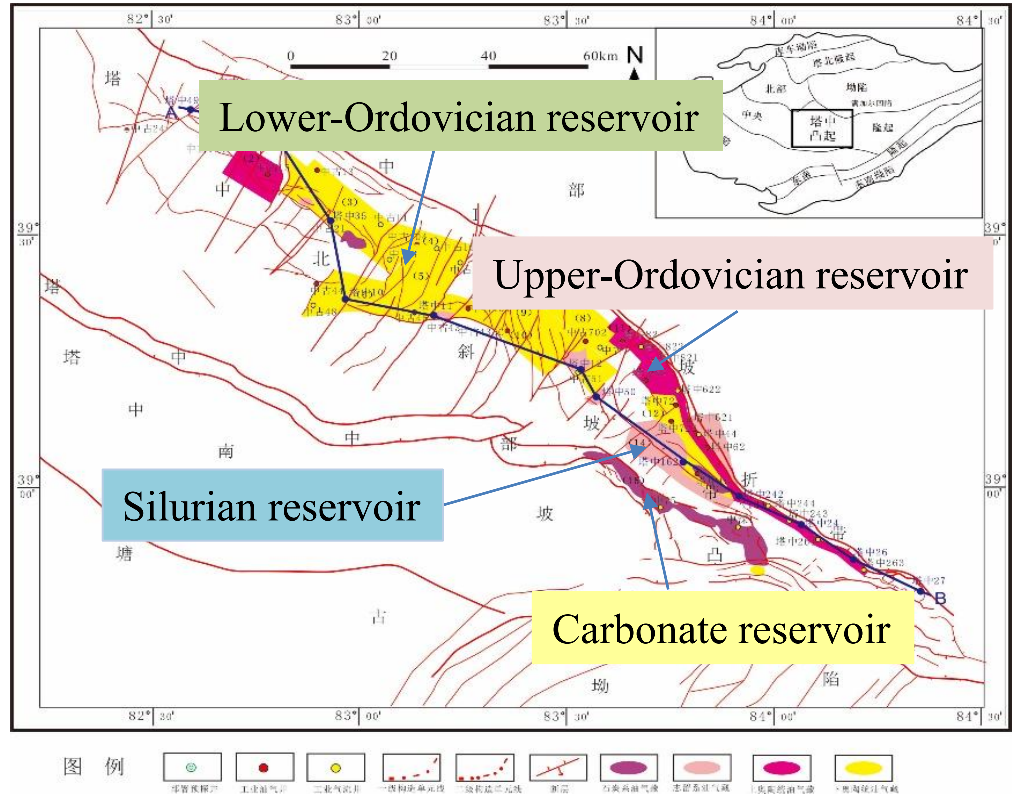
2. Geological background

Oil&gas occurrence layers and blocks

Wellblock	layer	Gas reserves ($\times 10^8 m^3$)	Oil reserves ($\times 10^4 t$)	oil equivalent ($\times 10^4 t$)	Total amount ($\times 10^4 t$)
Tazhong 4	C	23	3865	4056	4775
Tazhong40				719	
Tazhong 15-16	S		1217	1217	1217
Tazhong 86-45	O3	230	2262	4100	33709
Zhonggu 15		62	1816	2311	
Zhonggu 2		151	122	1329	
Tazhong 82-26		805	4020	10452	
Tazhong 72-16		1822.48	955.76	15517	
Tazhong 83	O1	317	820	3346	54023
Zhonggu 5-7		539	1560	5856	
Zhonggu 51		1130	7877	16906	
Zhonggu 43		1158	6014	15267	
Zhonggu 10		840	2310	9022	
Zhonggu 8-21		317	1093	3626	



Total amount of oil&gas in Tazhong: 1.041 billion tons;

In the plane: 12 fault blocks in Tazhong area

Vertically: $C+S+O_1+O_3$

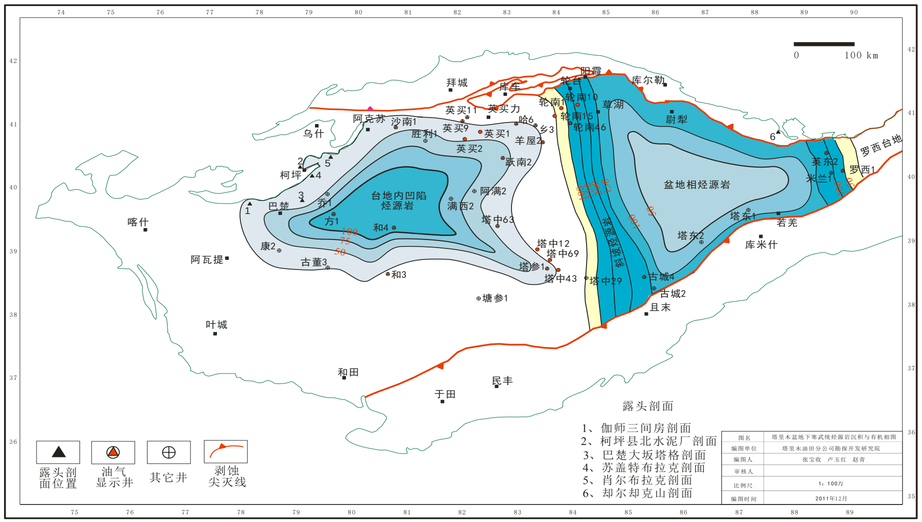
Oil&gas reserves in O_3: 0.337 billion tons,

Oil&gas reserves in O_1: 0.54 billion tons.

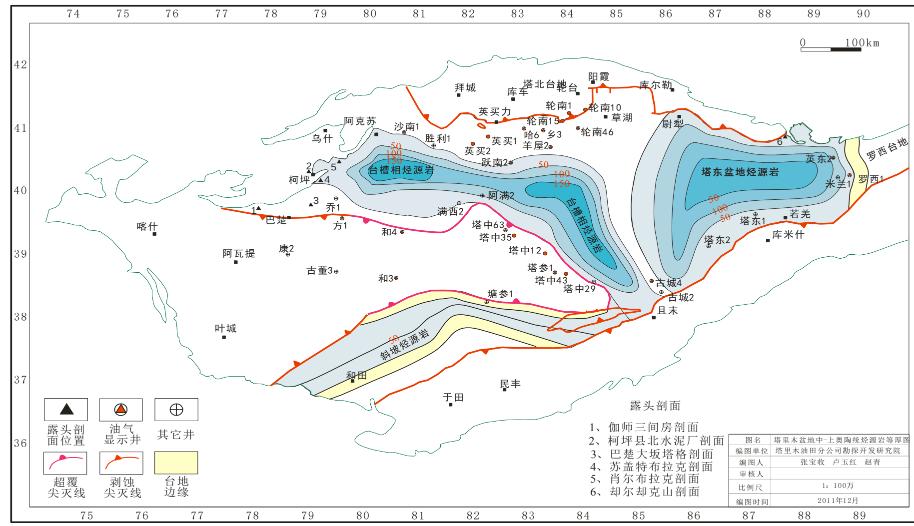
2. Geological background

Geological characteristics

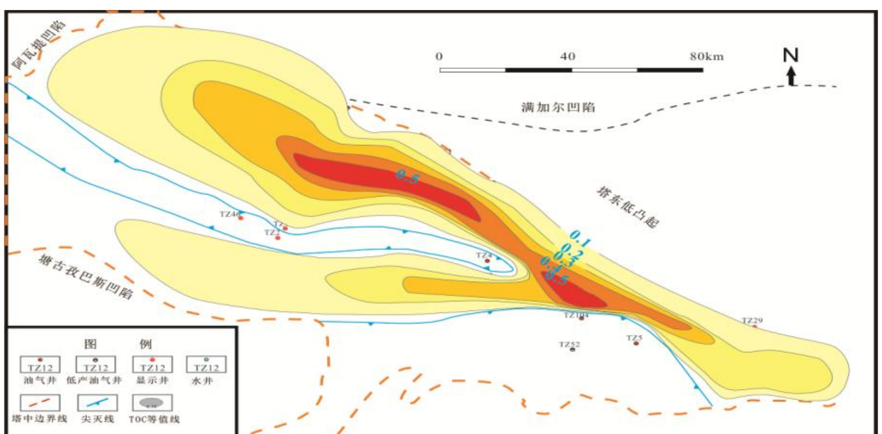
- ➢ **Source rocks in Tazhong are widely distributed, the range and thickness of Cambiran source rocks are both larger than the Ordovician source rocks.**
- ➢ **Source rocks with high abundance (TOC>0.5%) is distributed limitly, however, the low-abundance (TOC≤0.5%) source rocks is larger.**



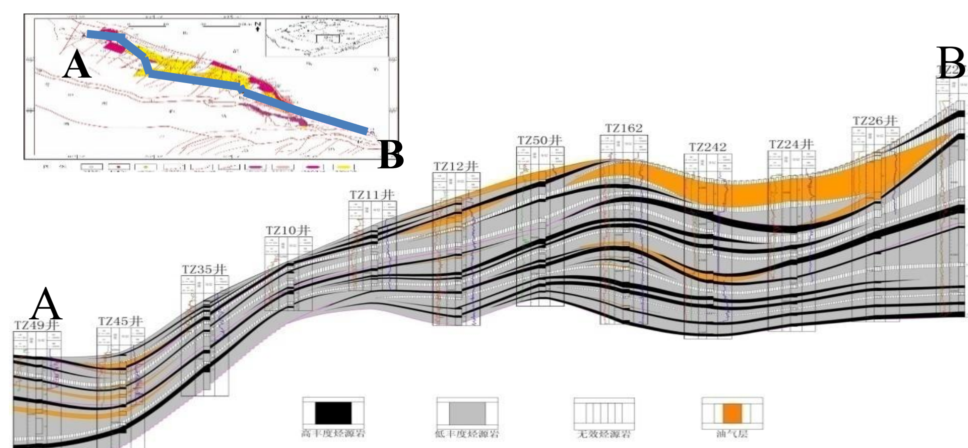
Thickness distributions of $\in_1$ source rocks in Tazhong



Thickness distributions of O_{2+3} source rocks in Tazhong



TOC distributions of O_{2+3} source rocks in Tazhong

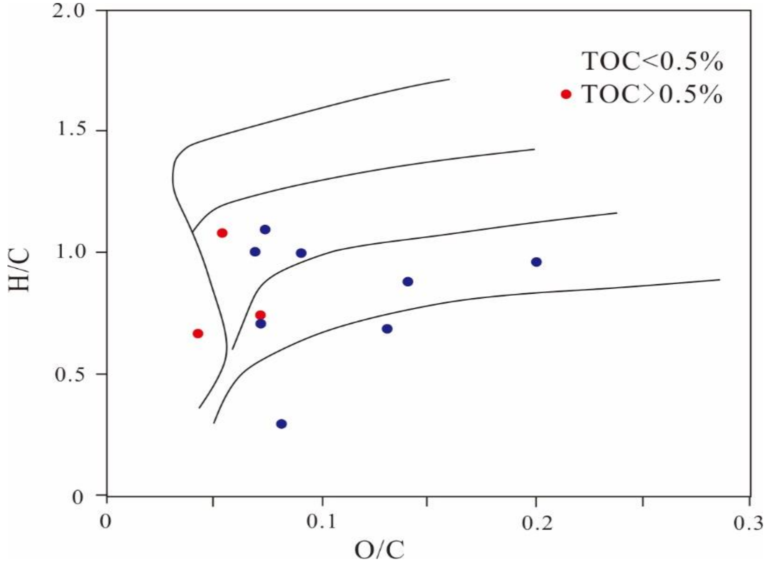


Thickness profile of O_{2+3} source rcoks in Tazhong

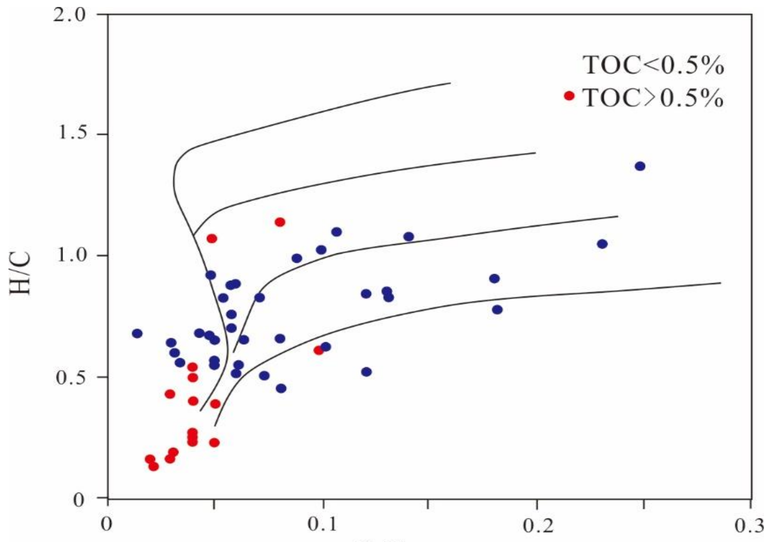
2. Geological background

Geochemical characteristics

Organic type

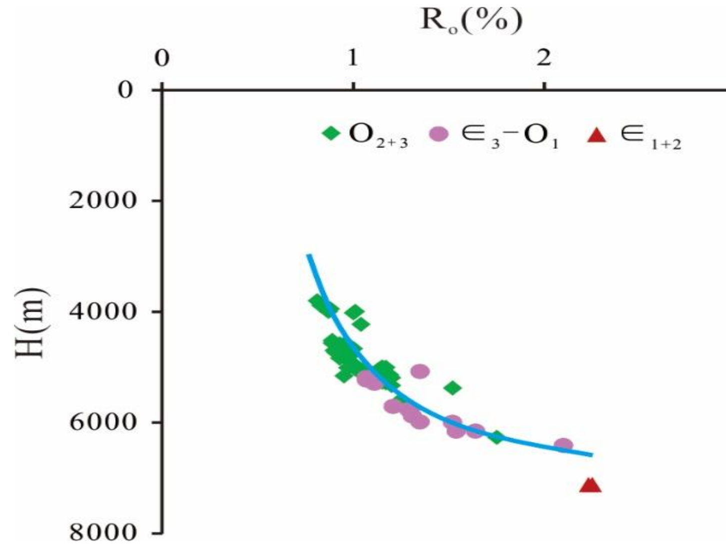


O_{2+3}: type I and II_2-III

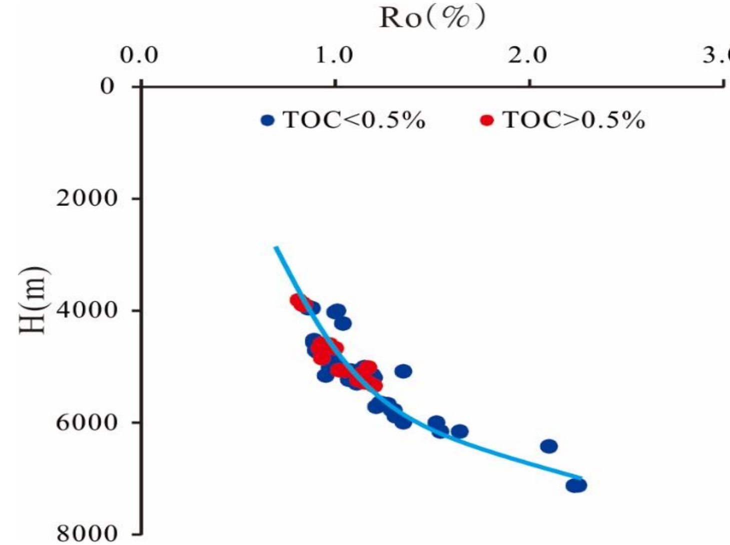


$\in_3$-O_1: mainly type I

Organic maturity



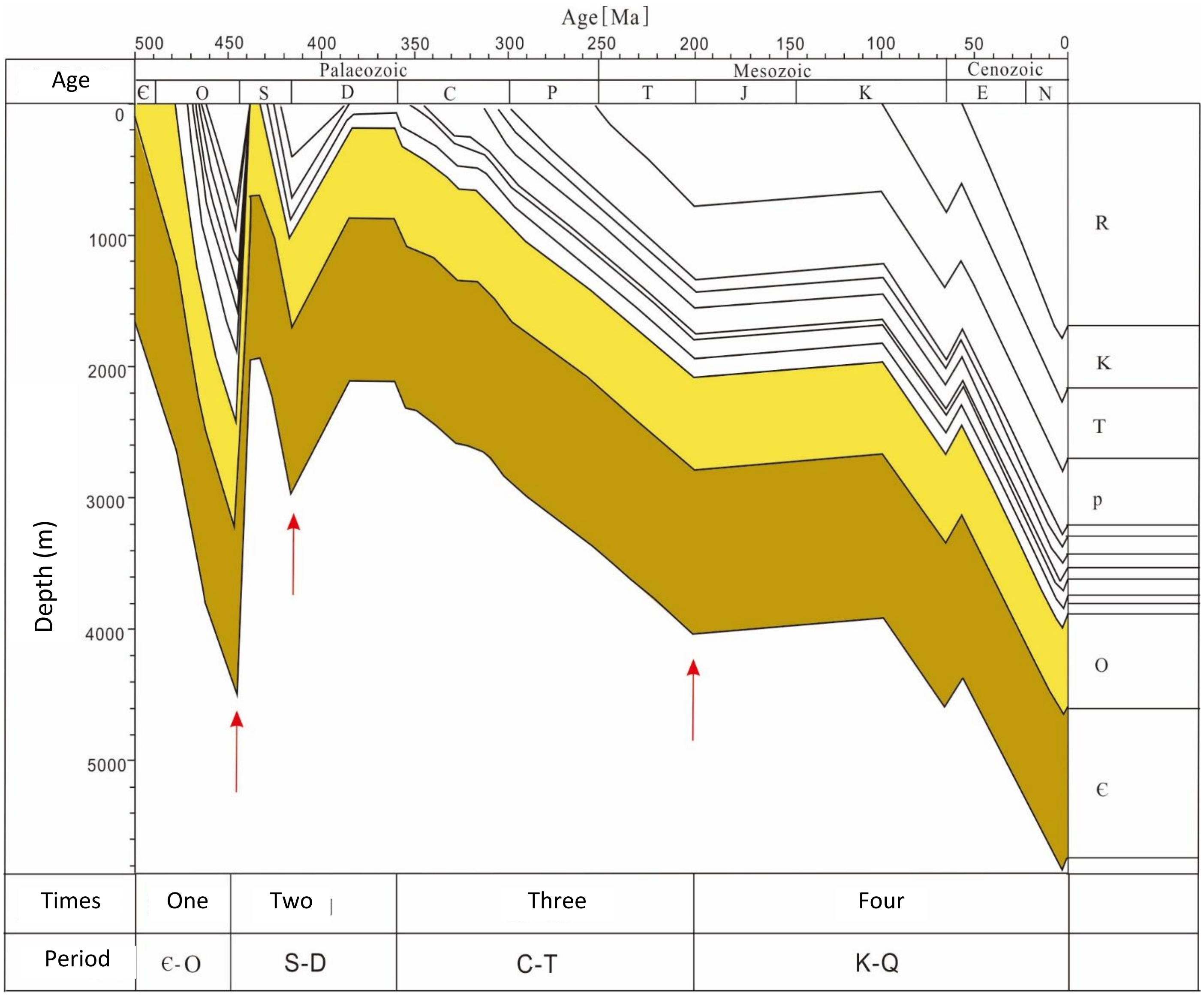
Mature-high mature, no difference amoung layers



Mature-high mature, no difference amoung organic abundance

2. Geological background

Thermal evolutionary history



✓ 3 times of tectonic events

✓ 4 periods of accumulation

Period 1: ∈-O

Period 2: S-D

Perios 3: C-T

Period 4: K-Q

Outline

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3.Methods

➢ **Forward analysis method of calculating relative contributions of multi-source oil&gas**

Hydrocarbon expulsion Qe → Effective hydrocarbon expulsion Qes → Available hydrocarbon accumulation Qa → Prospective Resources Q

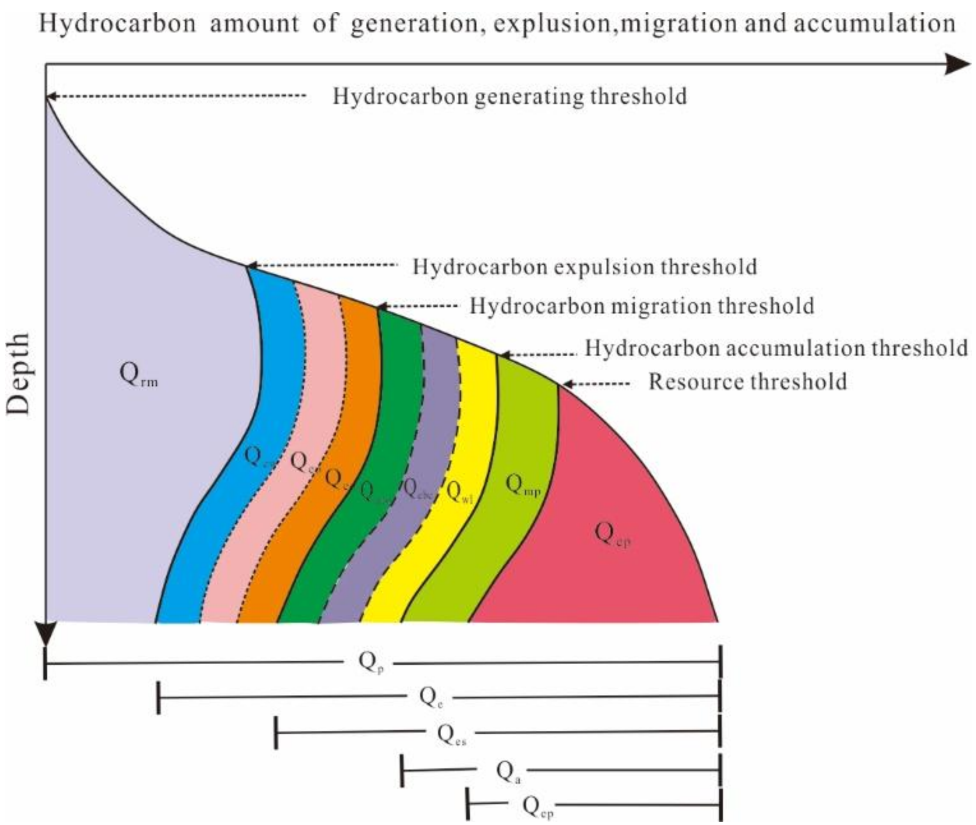
Relative conrtibution: $K_i = \frac{Q_i}{\sum Q_i}$

$$Q_e = Q_p - Q_{rm}$$

$$Q_{es} = Q_e - Q_{ew} - Q_{ed} - Q_{eo}$$

$$Q_a = Q_{es} - Q_{rs} - Q_{bc} - Q_l$$

$$Q = Q_a - Q_{ds}$$



Q_p Hydrocarbon generation

Q_{rm} Hydrocarbon remaining

Q_{ew} Water soluble phase hydrocarbon expulsion

Q_{ed} Diffusion phase hydrocarbon expulsion

Q_{eo} Oilsoluble phase hydrocarbon expulsion

Q_{rs} Retained hydrocarbon content of reservoir

Q_{bc} Hydrocarbon loss amount before covering

Q_l Hydrocarbon dissipation amount by migration

Q_{ds} Destroyed hydrocarbon amount by tectonic events

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Hydrocarbon generation amount based on material balance and optimization simulation

Principle of mass balance

Main elements: C, H, S, N, O (sum>99.5%).

Primary kerogen
(C_o, H_o, O_o, N_o, S_o)

||

CH_4, C_2H_6, C_3H_8, C_4H_{10}, CO_2, H_2S, N_2, H_2, H_2O, OIL
(sum>99.5%)

+

Other products
(sum<0.5%)

+

Residual kerogen
(C_i, H_i, O_i, N_i, S_i)

Suppose: Only consider the formation of the above ten products

Calculation method of optimization simulation

Mass conservation

$$M_0=M_i+\sum X_i \quad \text{①}$$

Element conservation

$$\sum_{i=1}^{10} K_{Ci}\cdot X_i \le M_0\cdot(K_{C0}-K_C)+\Delta M\cdot K_C \quad \text{②}$$

$$\sum_{i=1}^{10} K_{Hi}\cdot X_i \le M_0\cdot(K_{H0}-K_H)+\Delta M\cdot K_H \quad \text{③}$$

$$\sum_{i=1}^{10} K_{Oi}\cdot X_i \le M_0\cdot(K_{O0}-K_O)+\Delta M\cdot K_O \quad \text{④}$$

$$\sum_{i=1}^{10} K_{Ni}\cdot X_i \le M_0\cdot(K_{N0}-K_N)+\Delta M\cdot K_N \quad \text{⑤}$$

$$\sum_{i=1}^{10} K_{Si}\cdot X_i \le M_0\cdot(K_{S0}-K_S)+\Delta M\cdot K_S \quad \text{⑥}$$

Geochemical constrains

$$X_i/X_1=k_i \quad i=2,3,4 \quad \text{⑦}$$

$$X_5/X_9\le k_5 \quad \text{⑧}$$

$$\sum_{i=1}^{10} X_i\le \Delta M \quad \text{⑨}$$

$$X_8/\sum_{i=1}^{8} X_i=k_8 \quad \text{⑩}$$

$$X_{10}/\Delta M=k_{10} \quad \text{⑪}$$

Non-negative constrains

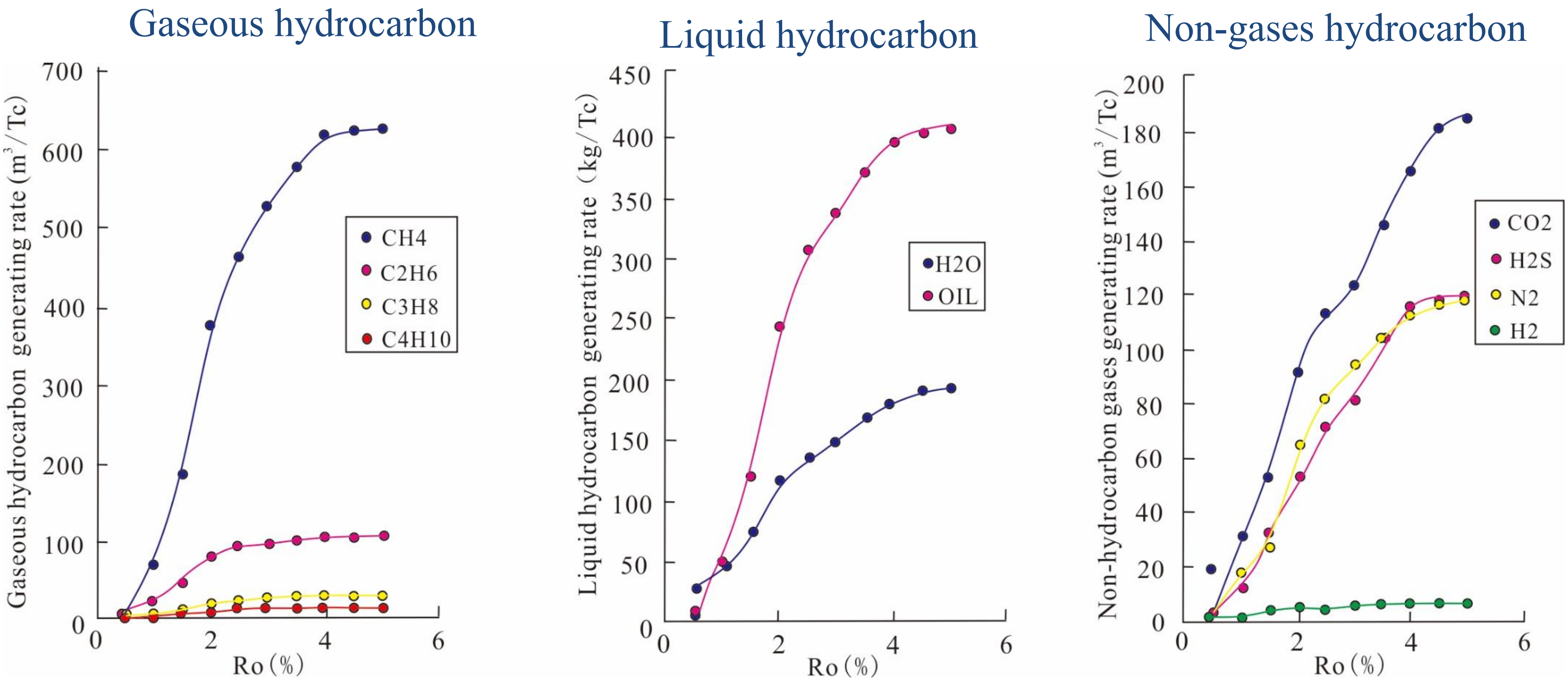
$$X_i\ge 0 \quad i=1,2,\cdots\cdots 10 \quad \text{⑫}$$

Objective function

$$\text{Min}(\S)=(M_0-M_i)-\sum Xi \quad \text{⑬}$$

4.Results

Hydrocarbon generation amount



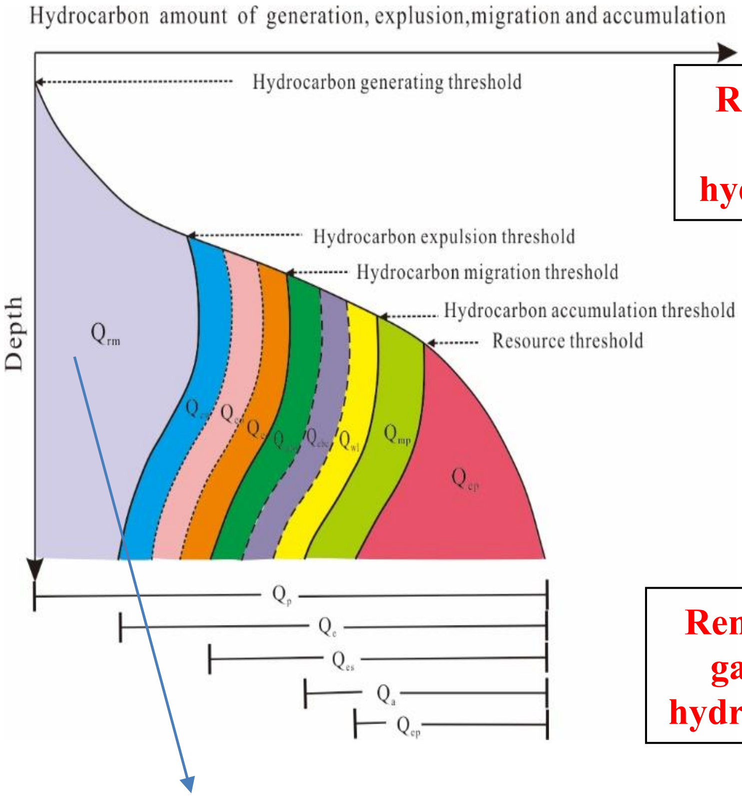
Hydrocarbon generation amount (generating rate) of source rocks in Tazhong area

For unit ton of organic matter (TOC), the generation amount of gaseous hydrocarbon, liquid hydrocarbon and non-gases hydrocarbon are 594m^3/T$_c$, 445kg/T$_c$ and 268m^3/T$_c$, respectively, when Ro is 2.5%;

When Ro is over 4.0%, the generating rate is rising slowly.

Hydrocarbon remaining amount based on phase simulation

The amount of remaining hydrocarbon is influenced by adsorption capacity of source rocks, dissolution capacity of pore water, capability of gas dissolving in oil, capillary sealing ability, etc.



Hydrocarbon remaining amount ???

Remaining liquid hydrocarbon

$$Q_{rm} = \rho_o \cdot (\phi_n + \Delta\phi) \cdot S_{om} \qquad S_{om} = f(C\%) \cdot \frac{1}{1 - B_k} \cdot e^{-\frac{\phi_n}{D}(R_o\% - R')^2}$$

$$f(C\%) = A_0 + A_1 \cdot C\% + A_2 \cdot (C\%)^2 \qquad B_k = 0.81 - 0.65R_o\% + 0.18(R_o\%)^2$$

Remaining gaseous hydrocarbon

Absorbed residual

$$Q_{wi} = K_i \cdot \rho_r \cdot K(C\%) \cdot \frac{K(R_o\%)}{K_w} \cdot \frac{a_i \cdot b_i \cdot p}{1 + b_i \cdot p} \cdot e^{-(T-20)}$$

$$K(R_o\%) = 0.836 + 0.68(R_o\%) + 0.498(R_o\%)^2$$

$$n = \frac{0.02}{0.993 + 0.0017p}$$

$$K_w = 1 + 0.445e^{1-p}$$

$$K(C\%) = A_0 + A_1 \cdot C\%$$

Water-soluble residual

$$Q_{wi} = q_{wi} \cdot \phi \cdot (1 - S_o)$$

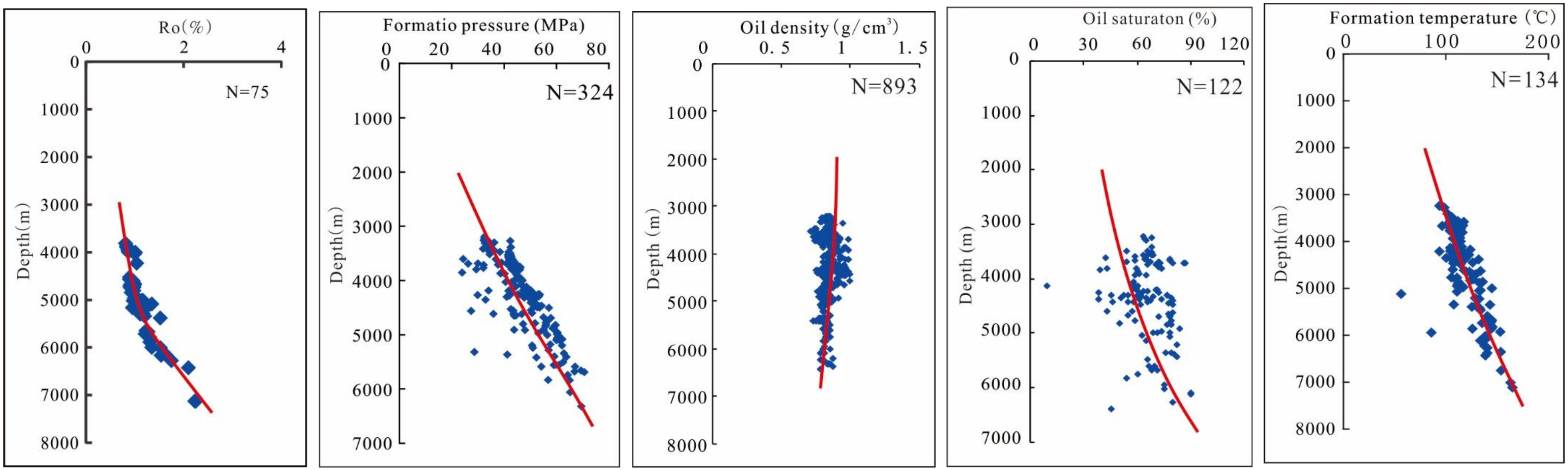
Oil-soluble residual

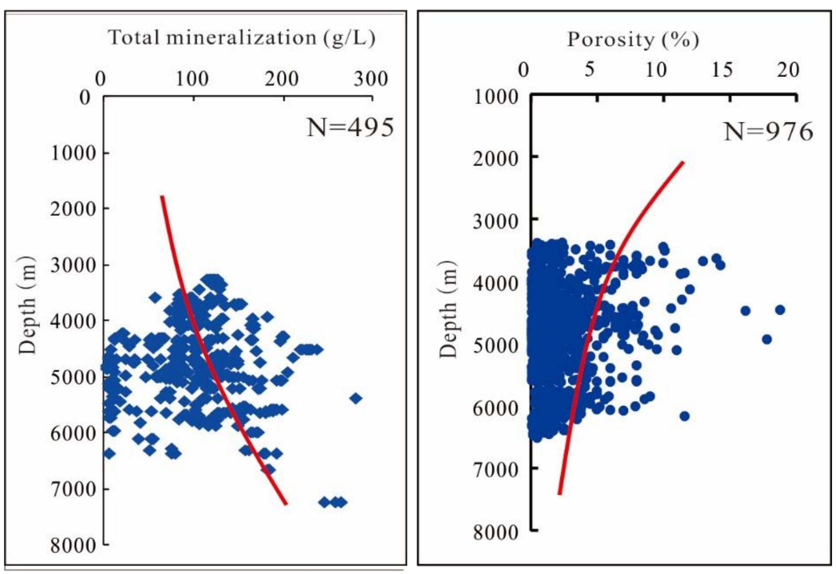
$$Q_{og} = q_{og} \cdot \phi \cdot S_o$$

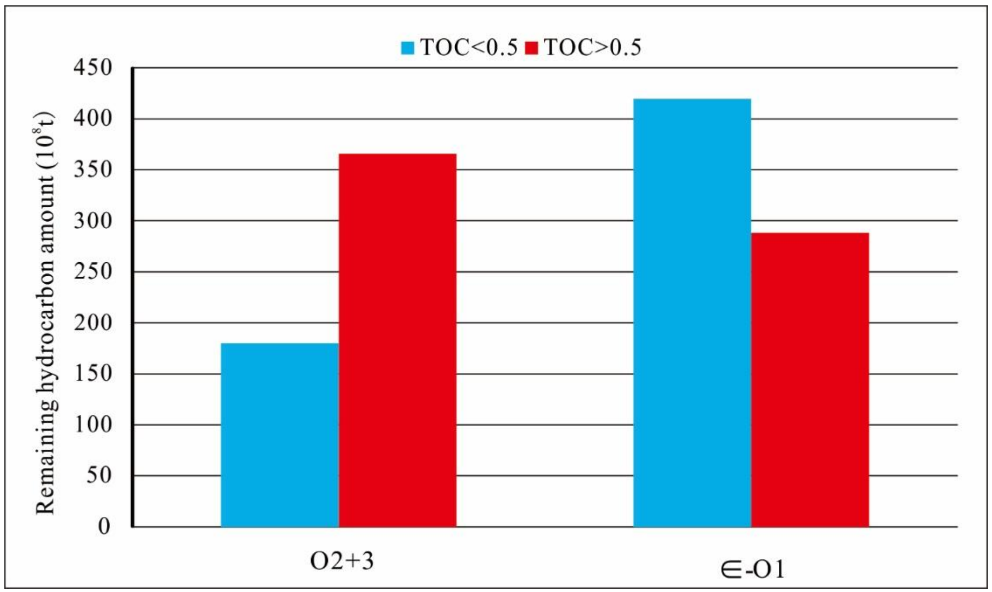
✓ **The above parameters are obtained by statistical or empirical data from study area.**

4.Results

Hydrocarbons remaining amount

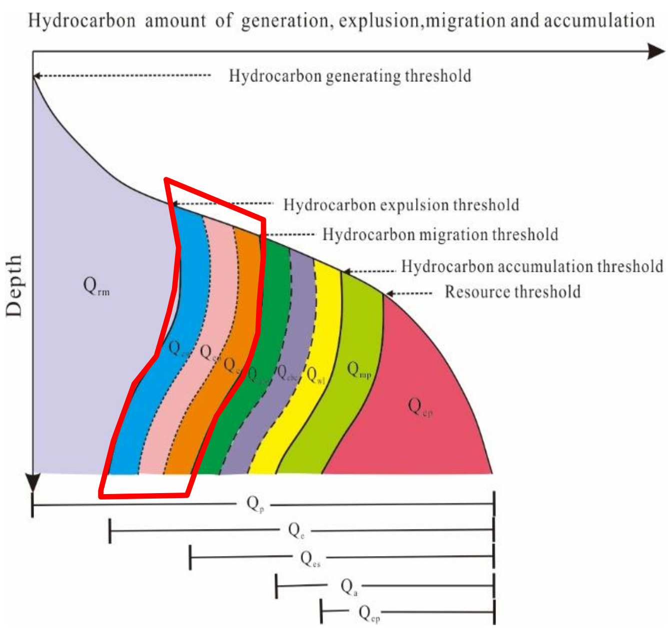






Hydrocarbon remaining amount of source rocks in Tazhong

Effective expelling amount obtained by oil&gas phase simulation



1) Hydrocarbon expulsion amount is the difference between the hydrocarbon generation amount and the hydrocarbon remaining amount.

2) Effective hydrocarbon expulsion amount is free-phase hydrocarbon expulsion amount.

$$Q_{es} = Q_e - Q_{ew} - Q_{ed} - Q_{eo}$$

Effective hydrocarbon explusion amount

???
Need calculation

Phases of hydrocarbon expulsion:

- **Diffusion phase** (Component/Temperature/pressure/ diffusion coefficient) → Invalid (Hunt,1979; Jones,1980; Barker,1980; Leythaeuser,1982)
- **Water-soluble phase** (Component/Temperature/pressure/ solubility coefficient) → Invalid (W.G.Dow,1974; R.W.Jones,1978; Tissot and Welte,1978; McAuliffe,1979;)
- **Gas dissolution in oil** (Component/Temperature/pressure/ solubility coefficient) → Invalid (Luo et al, 1985; Ungerer et al, 1990)
- **Free phase** (Component/Temperature/pressure/ total amount of hydrocarbon expulsion) → Effective (Dickey,1975; Magara,1977; R.W.Jones,1978; Barker,1980)

4.Results

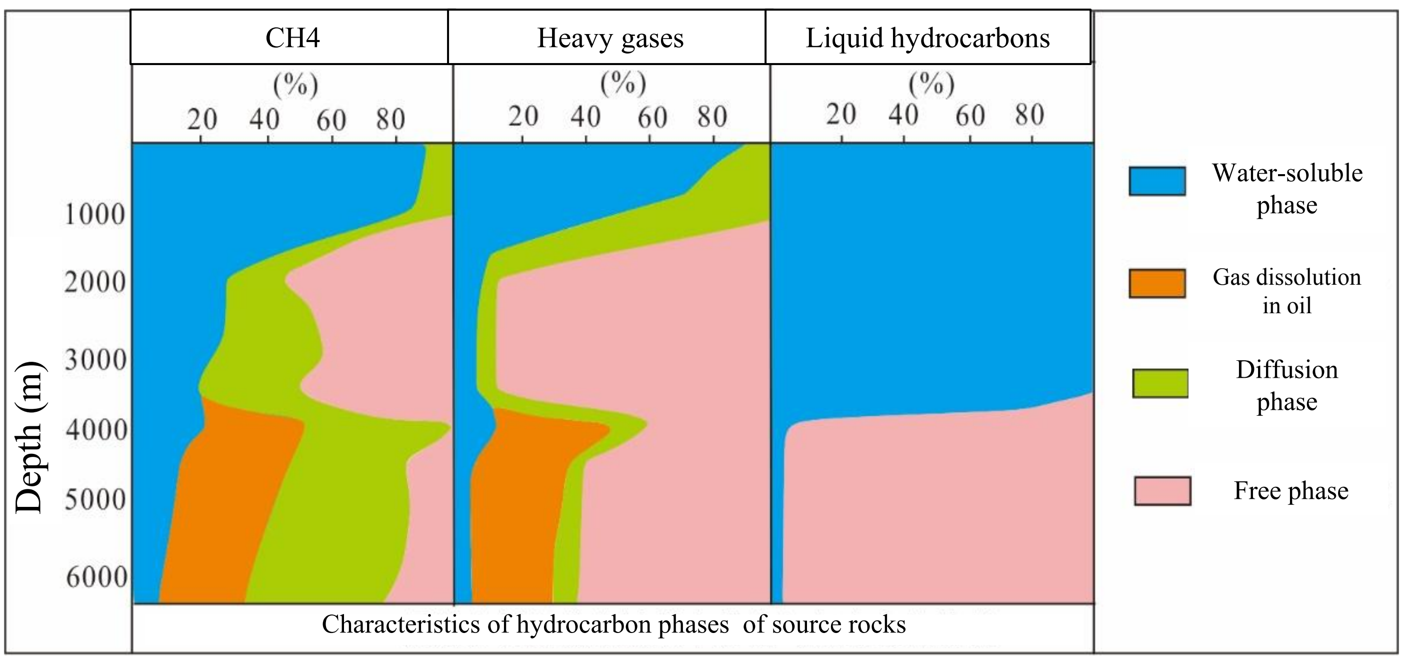
Oil/gas phase and effective expelling amount

Water-soluble phase hydrocarbon expulsion amount $$Q_{ew} = (Q_P + Q_{CW}) \cdot \sum_{1}^{4} q_w(i)$$

Gas expulsion amount dissolution in oil $$Q_{eo} = (Q_r - Q_{rm}) \cdot \sum_{1}^{4} q_o(i)$$

Diffusion phase hydrocarbon expulsion amount $$Q_{ed} = \int_0^t D \cdot \frac{dC}{dZ} \cdot H \cdot dt$$

Free phase hydrocarbon expulsion amount $$Q_{es} = Q_e - Q_{ew} - Q_{ed} - Q_{eo}$$



Characteristics of oil&gas phase in the process of hydrocarbon expulsion for source rocks in Tahzong

Effective rate of hydrocarbon expulsion

CH4: 50-70%

Heavy gases: 70-90%

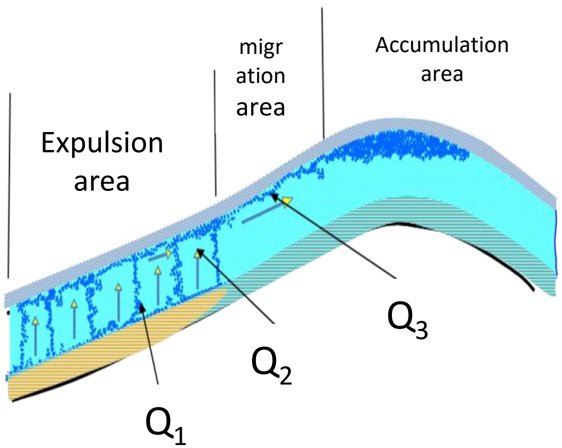
Liquid hydrocarbons: 90-95%

4.Results

Hydrocarbon migration loss amount based on predominant pathways simulation

Study distribution of the migration-loss hydrocarbon in the predominant pathways and propose calculation models and formulas

$$Q_{lt} = Q_{rs} + Q_{bc} + Q_l$$

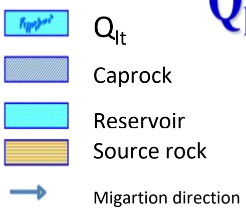


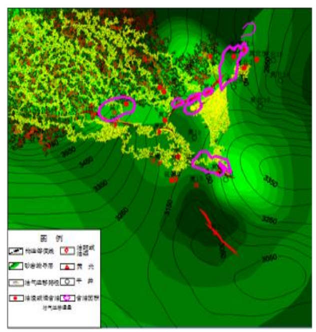
Q_1: vertical migration inside source rock

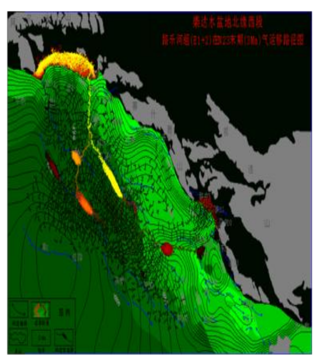
Q_2: lateral migration inside source rock

Q_3: lateral migration outside source rock

$$Q_{lb} = Q_1 + Q_2 + Q_3$$







Lekvam et al, 1997; Luo et al, 2008

1) Retained hydrocarbon content of reservoir Q_{rs}

$$Q_{rmo} = C_{path} \cdot S_L \cdot H_o \cdot \Phi \cdot S_o \cdot \rho_o$$

$$Q_{rmg}^{s} = C_{path} \cdot S_L' \cdot H_g \cdot (\Phi \cdot S_w \cdot q_w + \Phi \cdot S_o \cdot q_o + \Phi \cdot S_g \cdot \frac{273 \cdot P}{T})$$

2) Hydrocarbon loss amount before covering Q_{bc}

$$Q_{ebc} = \int_{t_0}^{t_1} q_e \cdot S_n dt$$

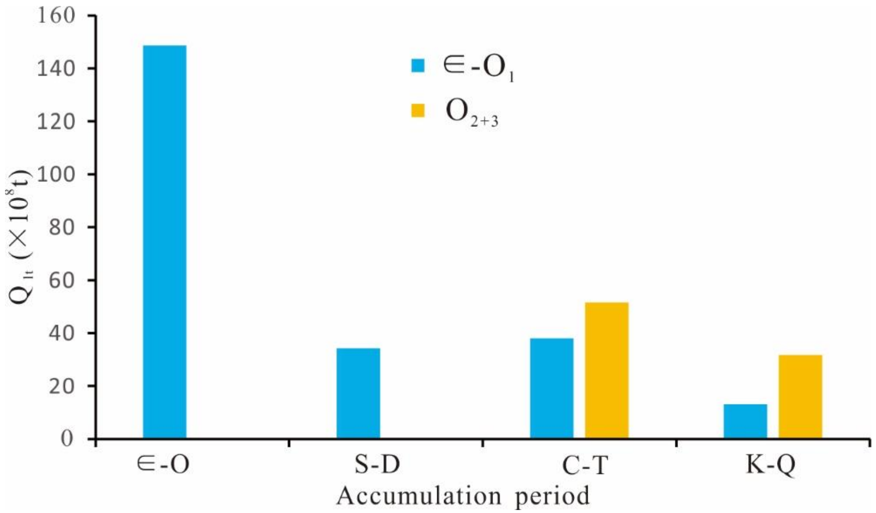
3) Hydrocarbon dissipation amount by migration Q_l

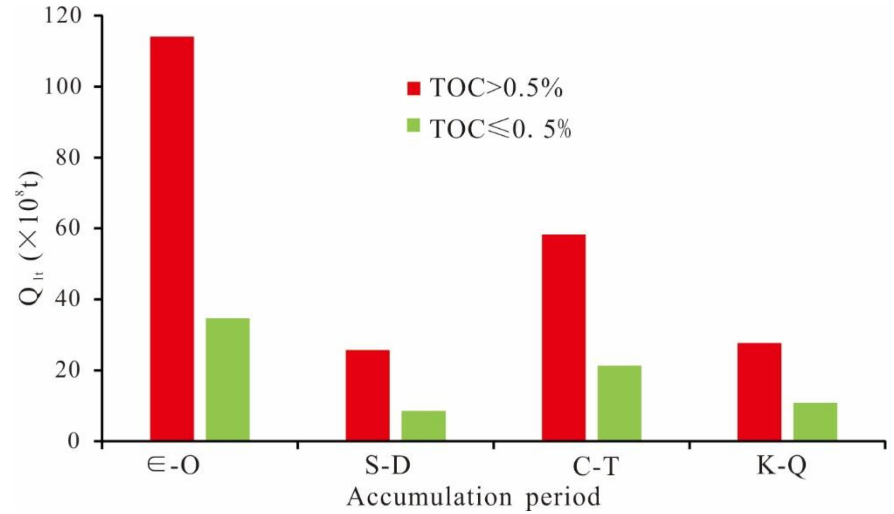
$$Q_{wl} = q_{ew} \cdot C_{path} \cdot S_L \cdot H \cdot \Delta\phi \cdot S_w$$

4.Results

Hydrocarbon migration loss amount

Amount of migration loss - hydrocarbon	Layers of source rocks	Accumulation period			
		∈-O	S-D	C-T	K-Q
$Q_{rs}+Q_{bc}$ ($\times 10^8$t)	∈-O_1	135.2	30.8	33.9	11.4
	O_{2+3}	0.0	0.0	46.9	28.3
Q_l ($\times 10^8$t)	∈-O_1	13.5	3.5	4.2	1.7
	O_{2+3}	0.0	0.0	4.7	3.5
Q_{lt} ($\times 10^8$t)	∈-O_1	148.8	34.3	38.1	13.1
	O_{2+3}	0.0	0.0	51.6	31.8





The amount of migration-loss hydrocarbon in Tazhong area

Destroyed hydrocarbon amount based on recovery of oil-water contact of reservoirs

$$Q = Q_a - \boxed{Q_{ds}}$$

The amount of destroyed hydrocarbon by 1st tectonism

$$Q_1 = Q_0 \cdot k_1$$

The cumulative amount of destroyed hydrocarbon after 2nd tectonism

$$Q_2 = Q_0 \cdot (1 - k_1) k_2$$

The cumulative amount of destroyed hydrocarbon after i times tectonism

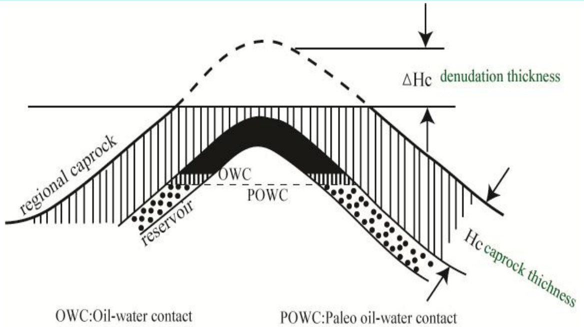
$$Q_i = Q_0 \cdot (1 - k_1)(1 - k_2) \Lambda \ k_i$$

Q_0: Resource amount of some layers;

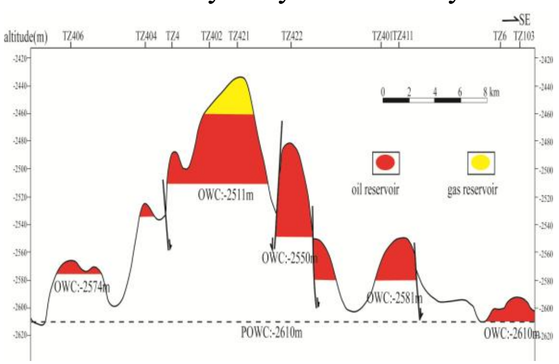
Q_i: The cumulative amount of destroyed hydrocarbon after i times tectonism

K_i: Rate of destroyed hydrocarbon in the i times tectonism

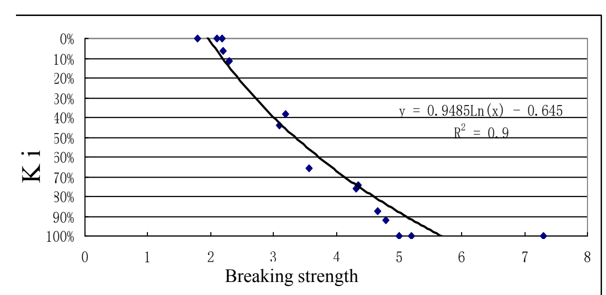
Breaking strength = denuded thickness / effective cover thickness



Geological model of destroyed hydrocarbon by tectonicsm



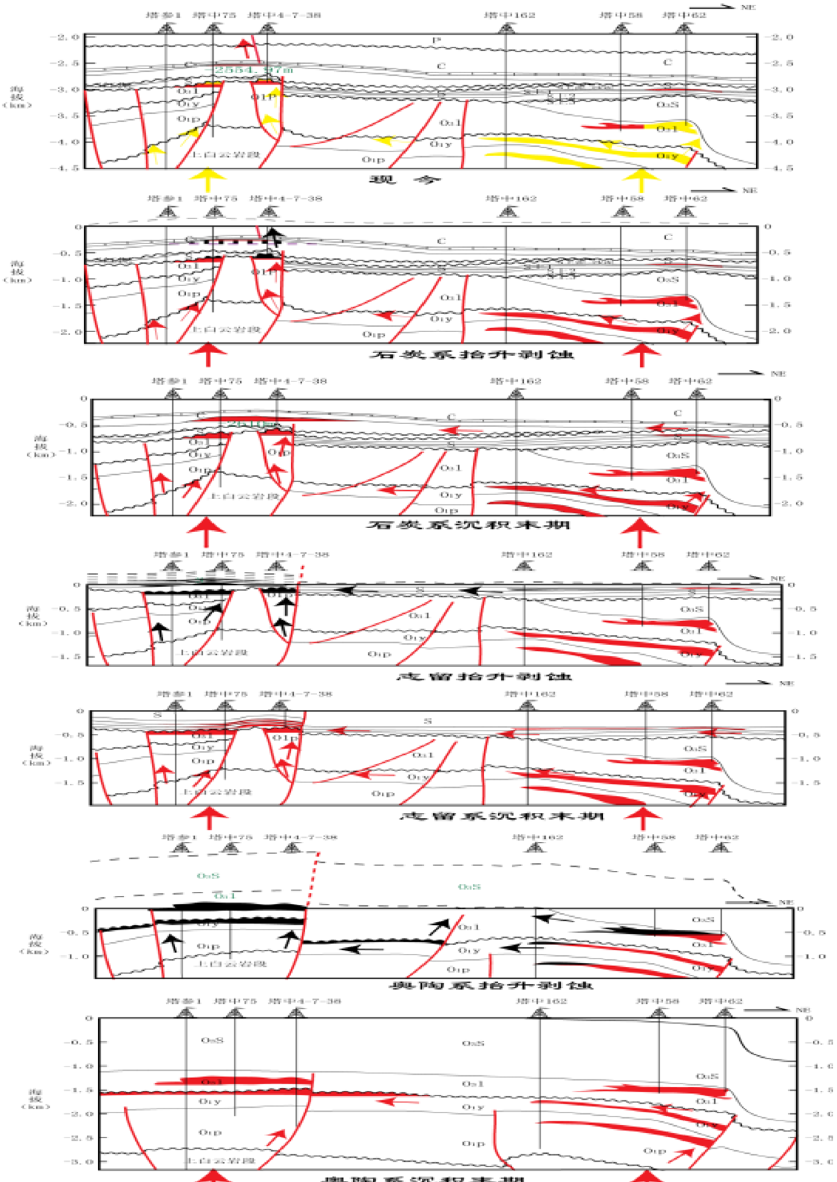
Recovery of oil-water contact of reservoirs by GOI



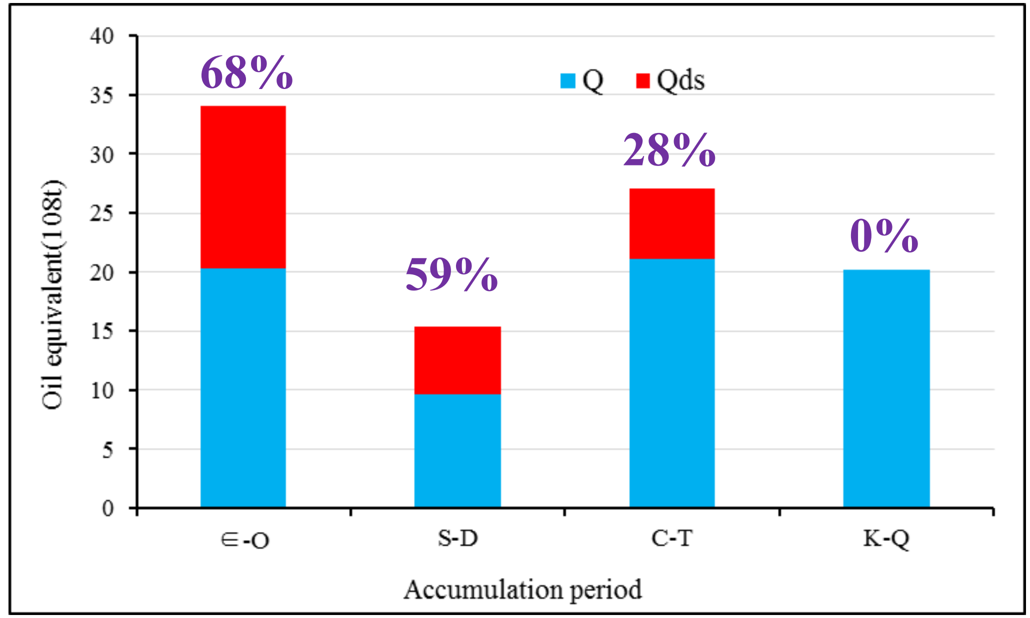
Calculation of rate of destroyed hydrocarbon

4.Results

Destroyed hydrocarbon amount



Processes of tectonic movements in Tazhong (Pang et al, 2012)



Amount of destroyed hydrocarbon and resources for each accumulation period in Tazhong area

The rate of destroyed hydrocarbon in ∈-O, S-D, C-T, K-Q is 68%, 59%, 28% and 0%, respectively. (Pang et al, 2012)

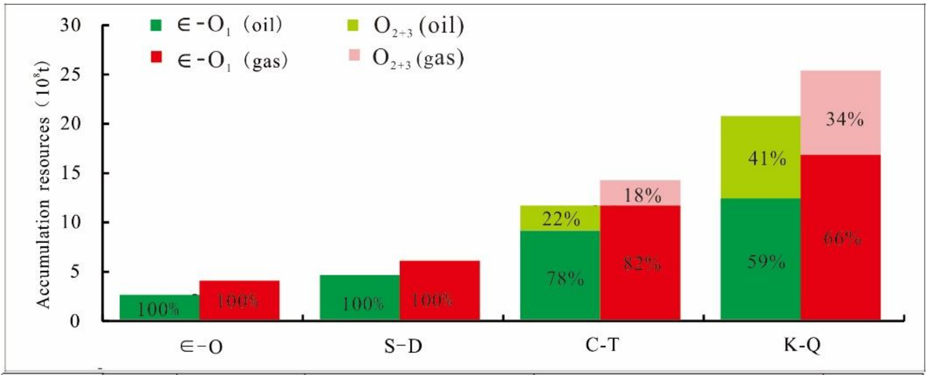
Outline

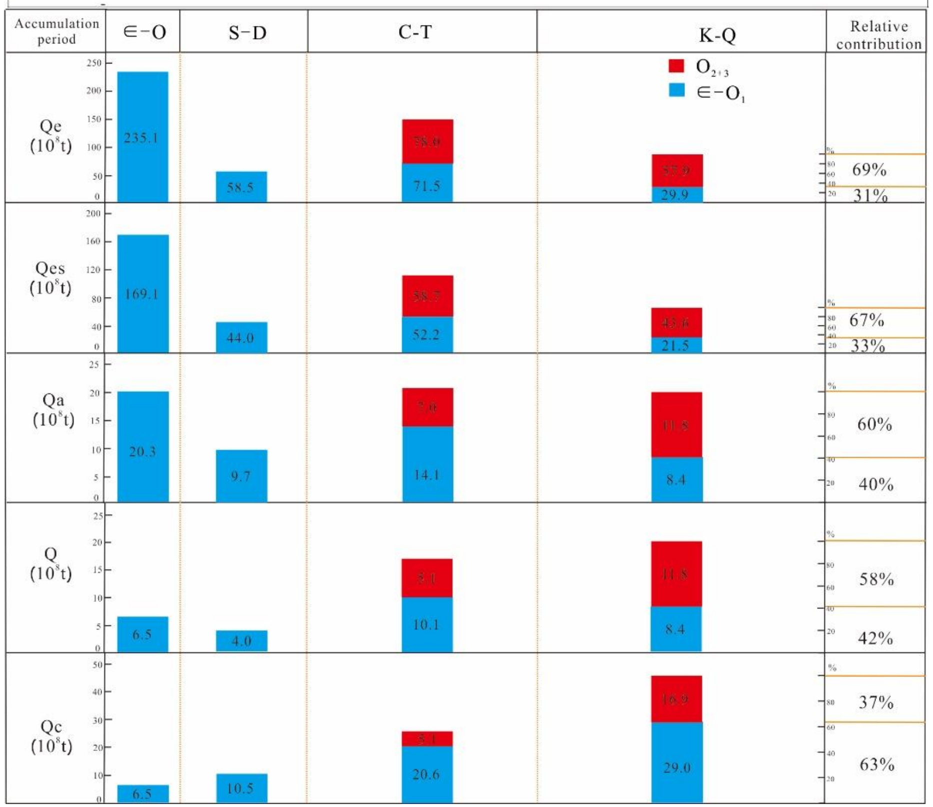
☞

1. Introduction
2. Geological background
3. Methods
4. Results
5. Discussion

5.Discussion

✓ The relative contribution of $\in$-O_1 source rock is higher than O_{2+3}



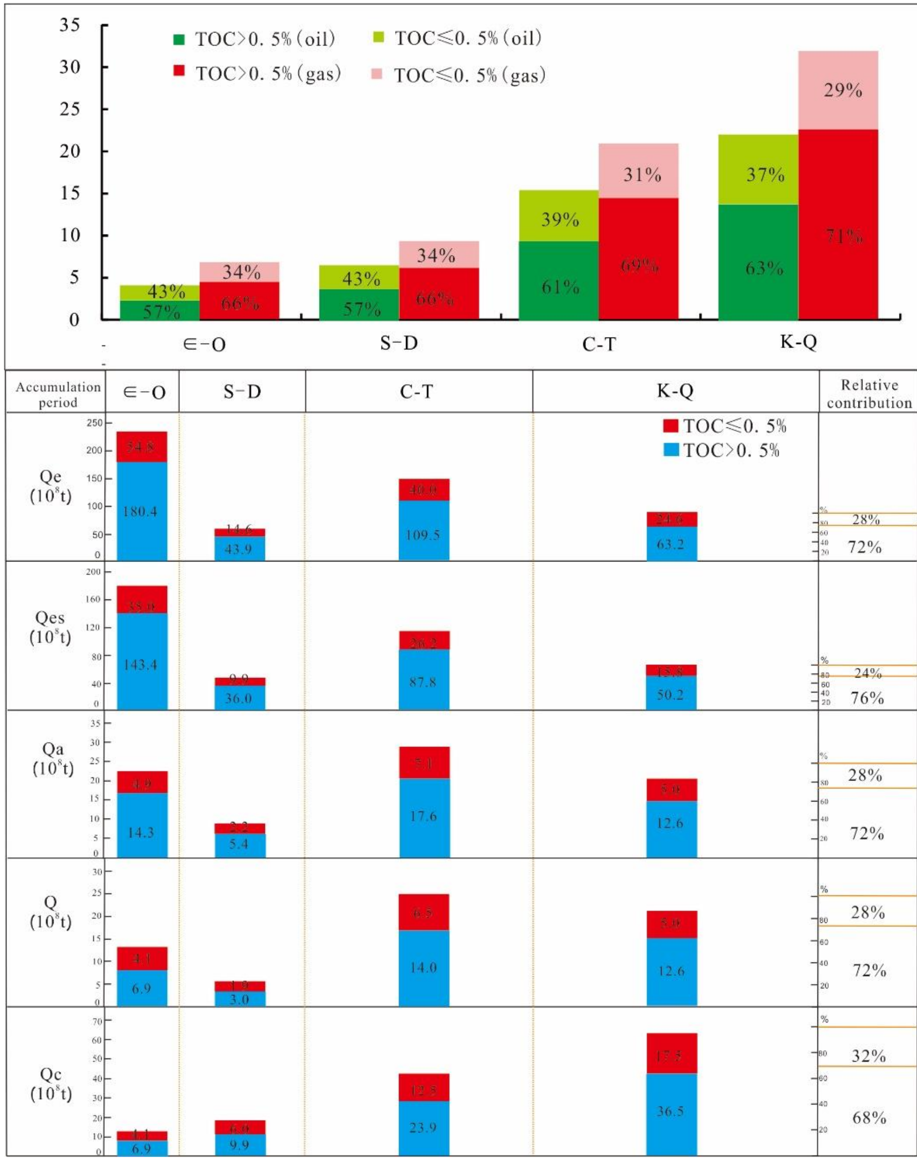


- ➢ For $\in$-O_1 source rock, the relative contribution in each accumulation period is 100%, 100%, 66% and 42%, respectively.
- ➢ The relative contribution of cumulative resources of $\in$-O_1 in the whole accumulation time is 63%.
- ➢ The relative contribution of $\in$-O_1 source rock is higher than the O_{2+3} source rock, so it can be inferred $\in$-O_1 is the main source of oil&gas in Tazhong.
- ➢ One of the reason that the petroleum reserves are larger than resources is some oil&gas comes from the Cambrian source rock.

Relative contribution of $\in$-O_1 : 67%
Relative contribution of O_{2+3} : 33%

5.Discussion

✓ Source rocks with low abundance (TOC≤0.5) also contribute to petroleum accumulation



- For source rocks with high abundance (TOC>0.5%), the relative contribution in each accumulation period is 63%, 61%, 68% and 72%, respectively.
- The relative contribution of cumulative resources of source rocks with high abundance (TOC>0.5%) in the whole accumulation time is 68%;
- The relative contribution of source rocks with high abundance (TOC>0.5%) is higher than source rocks with low abundance (TOC≤0.5%), but the latter can't be ignored.
- If source rocks with low abundance (TOC≤0.5%) is excluded when evaluating the resources, the resource potential can be underestimated.

Source rocks with high abundance (TOC>0.5%) : 68%
Source rocks with low abundance (TOC≤0.5%): 32%


Thank you
中国石油大学
Any questions?