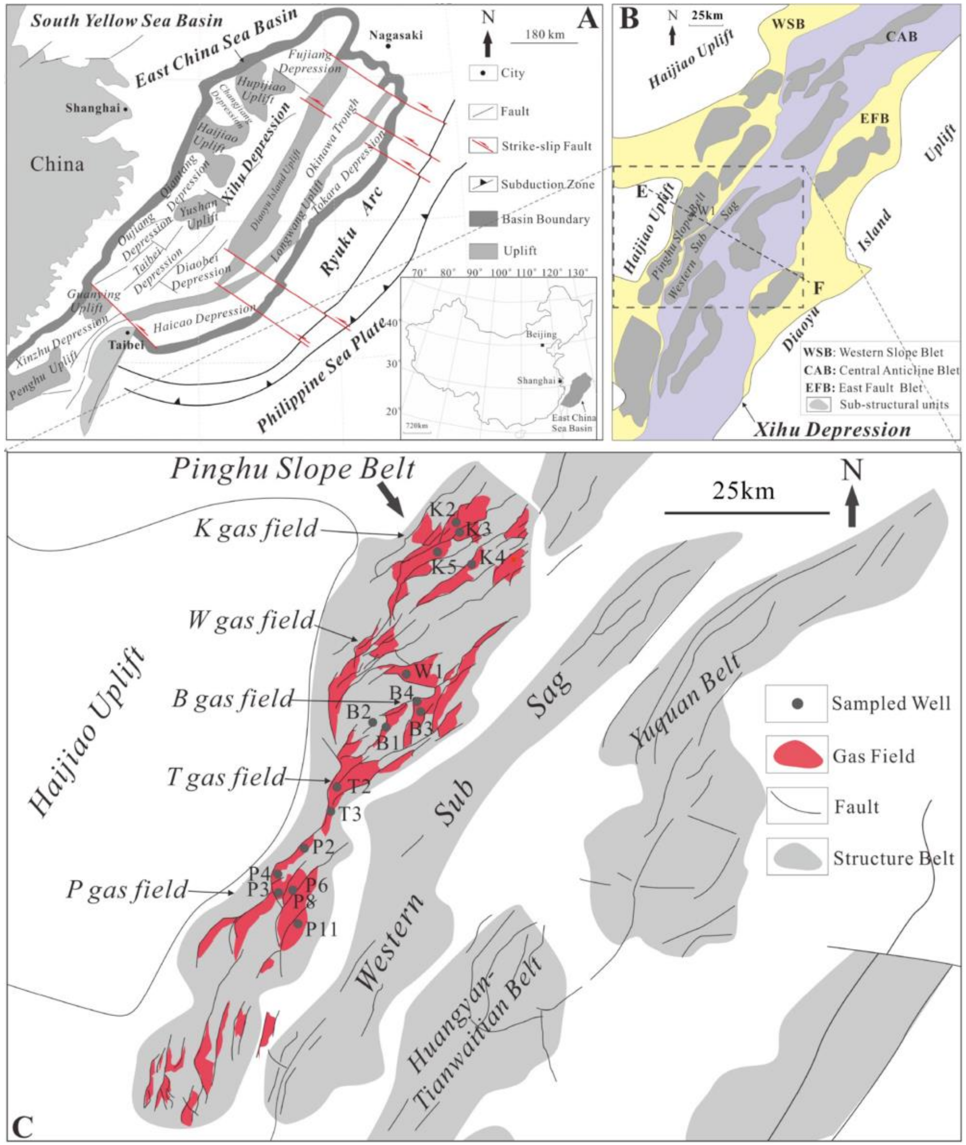
中国地质大学
CHINA UNIVERSITY OF GEOSCIENCES

SCHOOL OF
EARTH
RESOURCES

Simulation of hydrocarbon generation and expulsion for the dark mudstone with type-Ⅲ kerogen of Pinghu Formation in Xihu Sag, East China Sea Basin under near geological conditions

Chenjie Xu

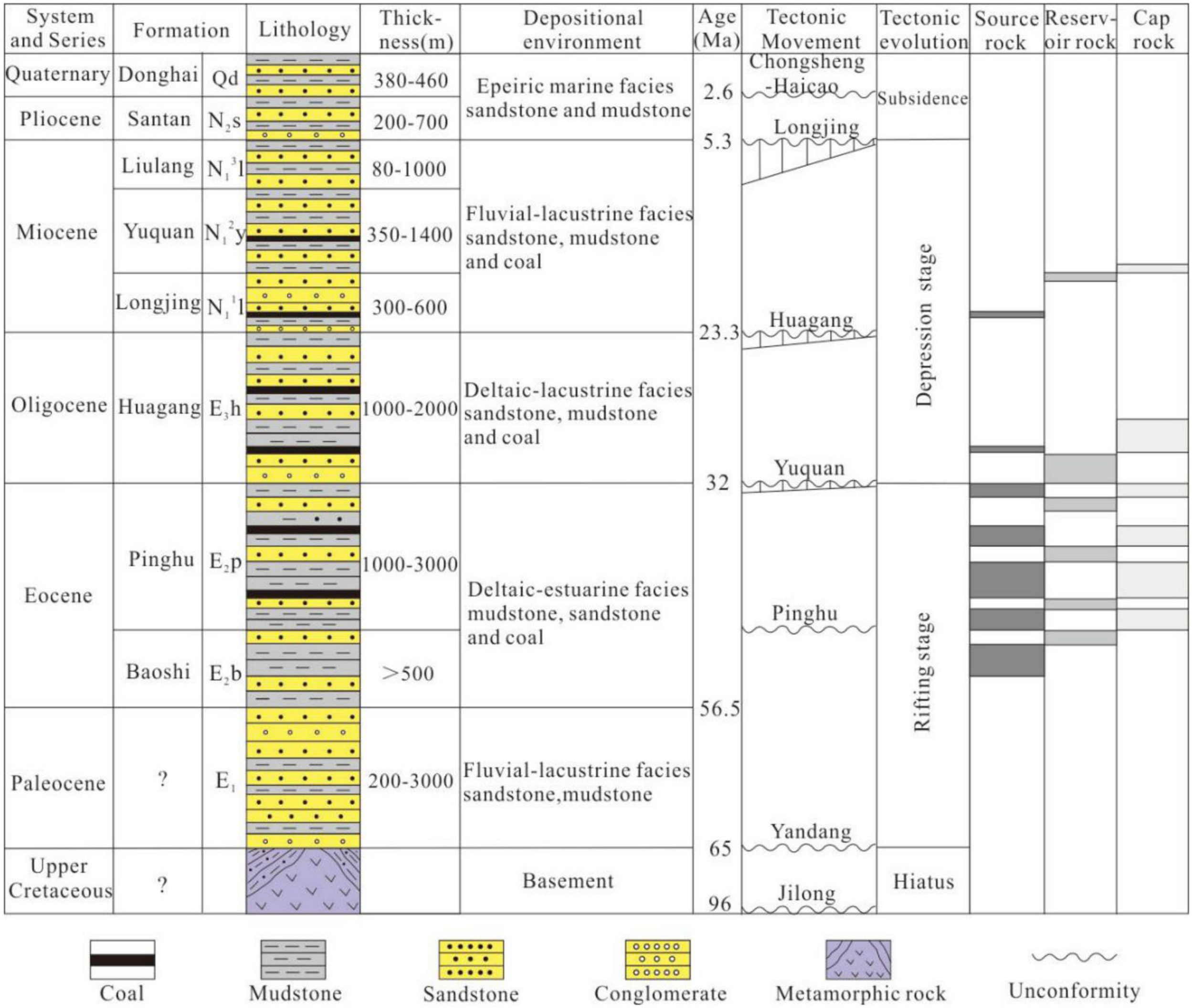
Geologic setting



A. Locations of the East China Sea Basin, plate boundaries, and major faults. B. Locations of sub-structure units and cross section E–F, in the Xihu Depression. C. Locations of the Pinghu slope belt, the five known gas fields, and faults. (Ao Su et al, 2019)

The East China Sea continental shelf basin is a Mesozoic–Cenozoic back-arc rift basin. It is the largest petroliferous basin in offshore China, with the central Xihu Depression being an exploration focus for decades (Li et al., 2009), and containing the renowned, giant Guzhenzhu gas field, as well as the large Chunxiao gas-condensate field (Zhang et al., 2013). The depression has a structurally bound, NE–SW trending, elongated shape (A and B), and covers an area of approximately 59,000 km^2. It is bound to the east by the Diaoyu Islands uplift, and to the North by the Fujiang Depression and the Hupijiao Rise Uplift (B and C). To the south, it is bordered by the Diaobei Depression, and to the west, it is connected to the Changjiang and Taibei depressions, and the Haijiao and Yushan uplifts. This region primarily yields natural gas, gas condensates, and light oils (Ye et al., 2007), and it is considered to be an underexplored hydrocarbon province, providing promising targets for future exploration in Eastern China.

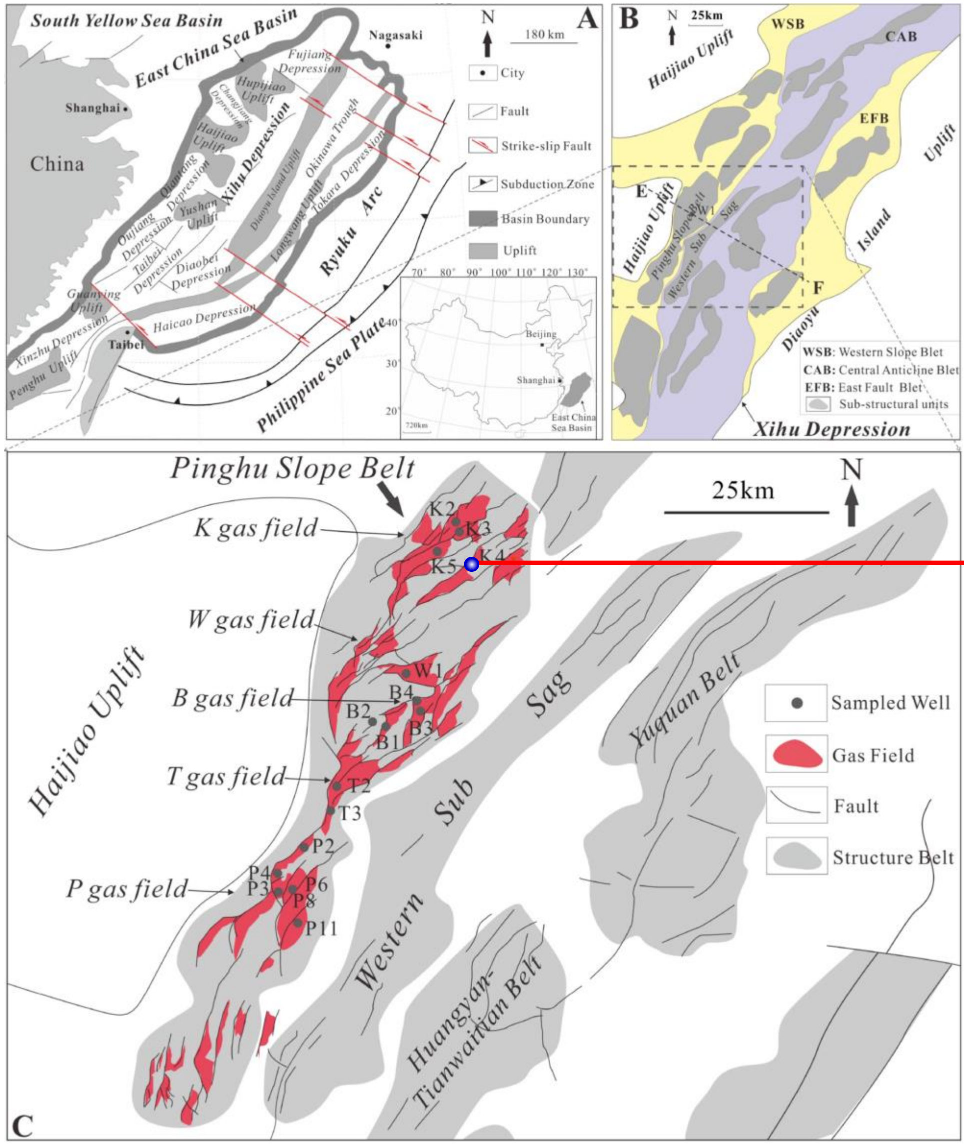
Geologic setting



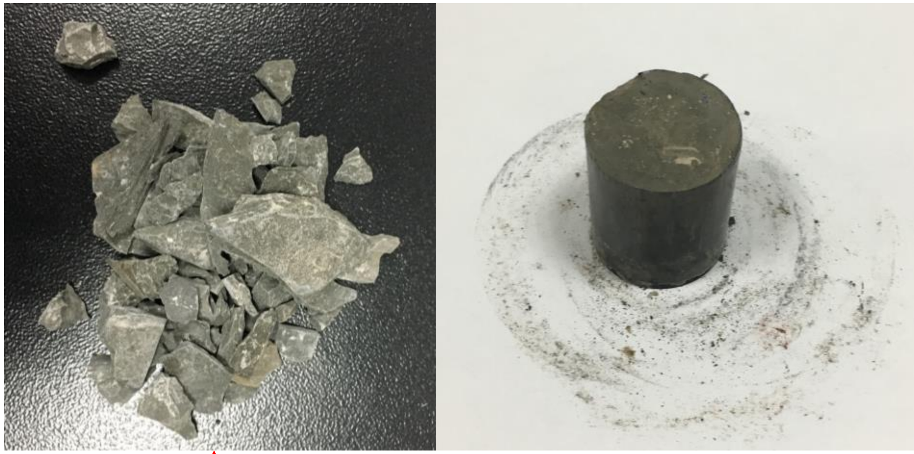
Stratigraphy, deposition, and tectonic evolution in the Xihu Depression. (Ao Su et al, 2019)

Siliciclastic deposition thickness within the Xihu Depression approaches 10,000 m. The stratigraphy of the depression is as follows: Paleocene Formation (E_1), the Eocene Baoshi (E_2b) and Pinghu (E_2p) Formations, and the Oligocene Huagang Formation (E_3h). The Longjing (N_1^1l), Yuquan (N_1^2y) and Liulang (N_1^3l) Formations make up the Miocene strata, with the Santan (N_2s) and Donghai (Qd) Formations deposited during the Pliocene and Quaternary (Ye et al., 2007). Present-day economic hydrocarbon reservoirs mostly occur in the sandstone intervals of the Huagang and Pinghu Formations. Coal measures, consisting of coal and dark carbonaceous mudstones within the Pinghu Formation, are considered to be the primary source rocks (Su et al., 2013).

Samples and analytical methods



A. Locations of the East China Sea Basin, plate boundaries, and major faults. B. Locations of sub-structure units and cross section E–F, in the Xihu Depression. C. Locations of the Pinghu slope belt, the five known gas fields, and faults. (Ao Su et al, 2019)



The dark mudstone with type-III kerogen in the Upper Member of the Pinghu Formation of the Well K4 in the Xihu Sag

TOC=0.68 %, HI=49 mg/g, Ro=0.75 %

Samples and analytical methods

DK formation porosity thermocompression hydrocarbon generation simulation experiment instrument

References to experimental instruments and principles

Zheng Lunju, Ma Zhongliang. Formation porosity thermocompression simulation experiment of hydrocarbon generation and expulsion, experimental geological technology of Wuxi Research Institute of Petroleum Geology, Sinopec [J]. Petroleum Geology & Experiment, 2010, 31(3): Inside cover.

Zheng Lunju, Qin Jianzhong, He Sheng, et al. Preliminary study of formation porosity thermocompression simulation experiment of hydrocarbon generation and expulsion [J]. Petroleum Geology & Experiment, 2009, 31(3)：296-306.

Ma Zhongliang, Zheng Lunju, Li Zhiming. The thermocompression simulation experiment of source rock hydrocarbon generation and expulsion in formation porosity [J]. ACTA Sedimentologica Sinica, 2012, 30(5): 955-963.

Samples and analytical methods

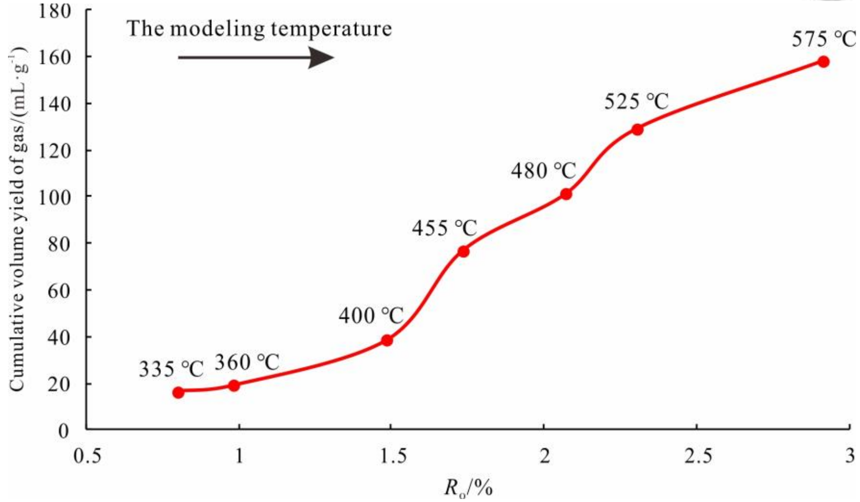
Scheme for simulation experiment of hydrocarbon generation and expulsion of dark mudstone with type-III kerogen in the Upper Member of the Pinghu Formation of the Well K4 in the Xihu Sag of East China Sea Basin

Number	The modeling depth /m	The modeling temperature /°C	Expected R_o /%	Lithostatic pressure /MPa	Pressure of hydrocarbon discharge kettle /MPa	Pressure difference of hydrocarbon expulsion /MPa	Temperature of hydrocarbon expulsion /°C	Soak Time /h	Weight /g
1	2 800	335	0.80	64.40	33.60	2.80	140	48	79.52
2	3 900	360	1.25	93.60	50.70	5.85	160	48	79.76
3	4 450	400	1.50	111.25	57.85	6.68	180	48	79.70
4	5 200	455	1.80	130.00	72.80	10.40	190	48	79.88
5	5 900	480	2.00	153.40	82.60	11.80	210	48	79.58
6	6 200	525	2.50	161.20	93.00	15.50	220	48	79.69
7	6 400	575	>3.00	166.40	96.00	16.00	220	48	79.62

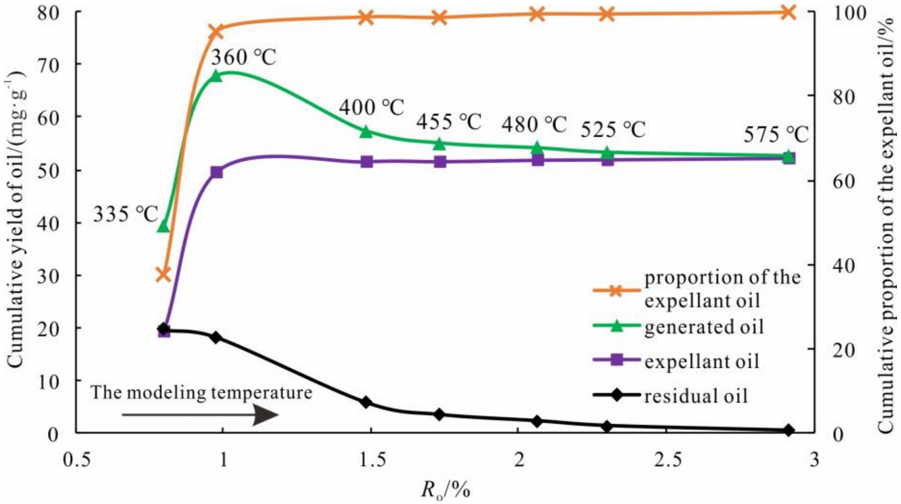
Simulation results of the Pinghu Formation dark mudstone with type-Ⅲ kerogen from the Xihu Sag of East China Sea Basin under the near geological conditions

Number	The modeling temperature /°C	R_o /%	Cumulative yield of the expellant oil /(mg • g^{-1})	Cumulative yield of the residual oil /(mg • g^{-1})	Cumulative yield of oil /(mg • g^{-1})	Cumulative proportion of the expellant oil /%	Cumulative volume yield of gas /(mL • g^{-1})	Cumulative yield of gas /(mg • g^{-1})	Methane content /%	Cumulative yield of hydrocarbons /(mg • g^{-1})
1	335	0.80	19.65	19.76	39.41	37.61	16.72	21.23	58.82	60.63
2	360	0.98	49.77	18.29	68.06	95.27	19.12	25.15	62.14	93.21
3	400	1.48	51.61	5.83	57.44	98.79	38.48	47.21	73.71	104.64
4	455	1.74	51.62	3.51	55.13	98.82	77.16	79.17	83.25	134.30
5	480	2.07	51.90	2.32	54.22	99.35	101.12	100.70	93.10	154.92
6	525	2.30	51.98	1.40	53.38	99.51	129.27	117.12	96.10	170.51
7	575	2.91	52.24	0.49	52.73	100.00	158.44	136.87	98.63	189.61

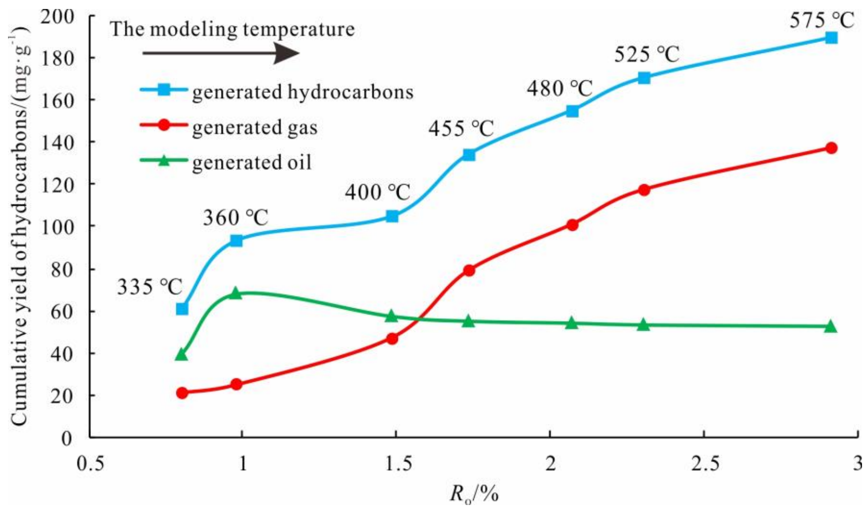
Results and discussion



Relationships between the cumulative volume yield of gas and R_o of the Pinghu Formation dark mudstone with type-III kerogen in the Xihu Sag of East China Sea Basin

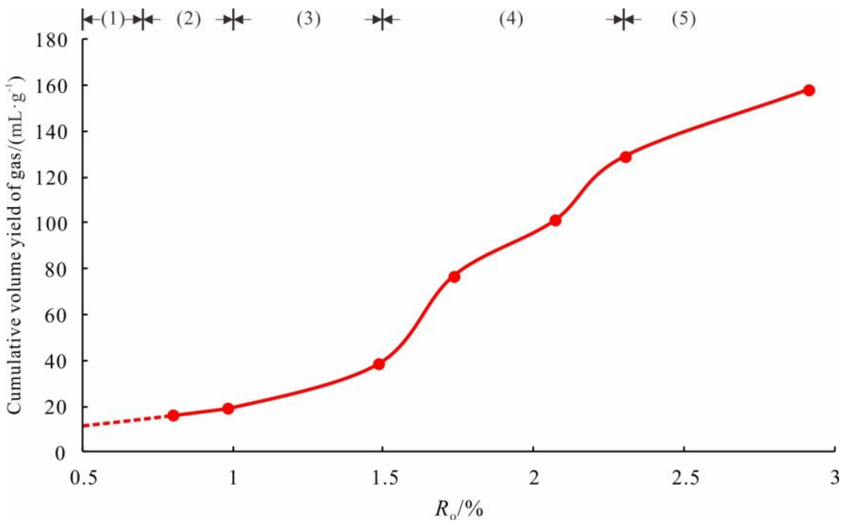


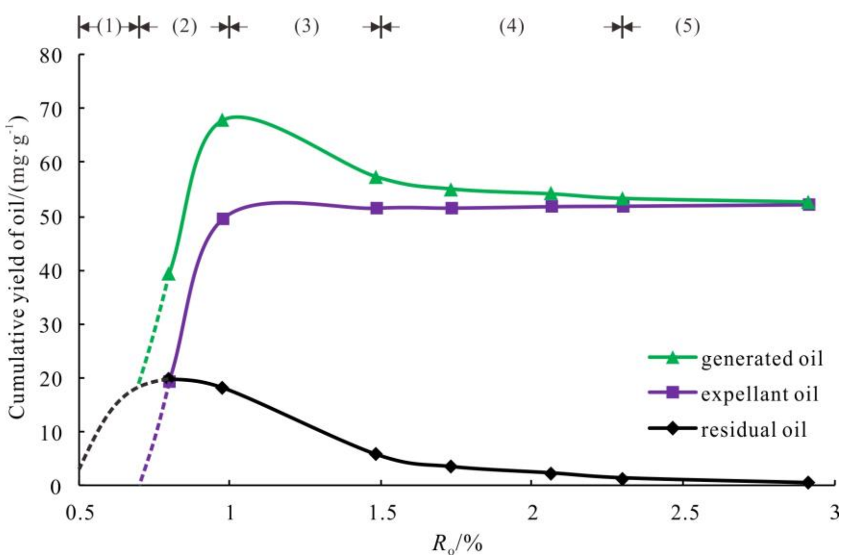
Relationships between the cumulative yield of oil and R_o of the Pinghu Formation dark mudstone with type-III kerogen in the Xihu Sag of East China Sea Basin



Relationships between the cumulative yield of hydrocarbons and R_o of the Pinghu Formation dark mudstone with type-III kerogen in the Xihu Sag of East China Sea Basin

Results and discussion





The results show that the process of hydrocarbon generation and expulsion can be divided into five stages as follows:

(1) R_o=0.5%-0.7%, oil is generated slowly and is not expelled;

(2) R_o=0.7%-1.0%, oil is generated and expelled rapidly;

(3) R_o=1.0%-1.5%, oil is checked into hydrocarbon gas;

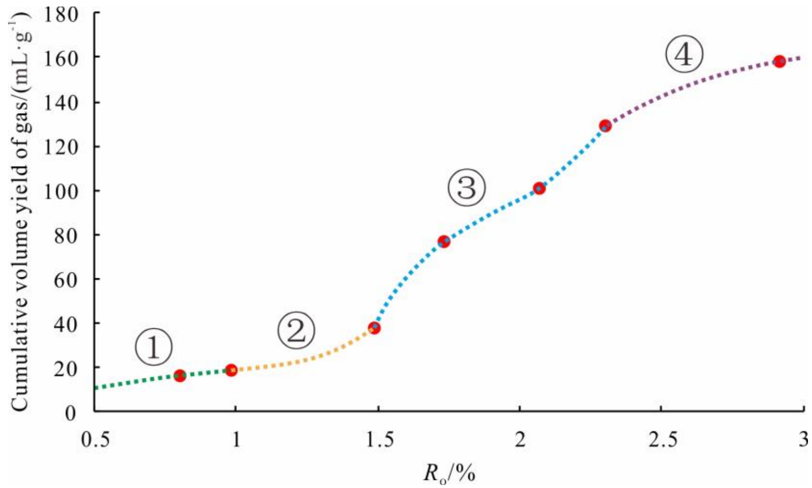
(4) R_o=1.5%-2.3%, natural gas is the main product;

(5) R_o>2.3%, only dry gas can be generated.

Hydrocarbon expulsion threshold of this kind of source rock is R_o=0.7%.

The dark mudstone of Pinghu Formation is a gas source rock which has a wide gas-window (R_o=1.0%-3.0%) and can maintain strong gas generation ability at high mature stage and over-mature stage.

Results and discussion



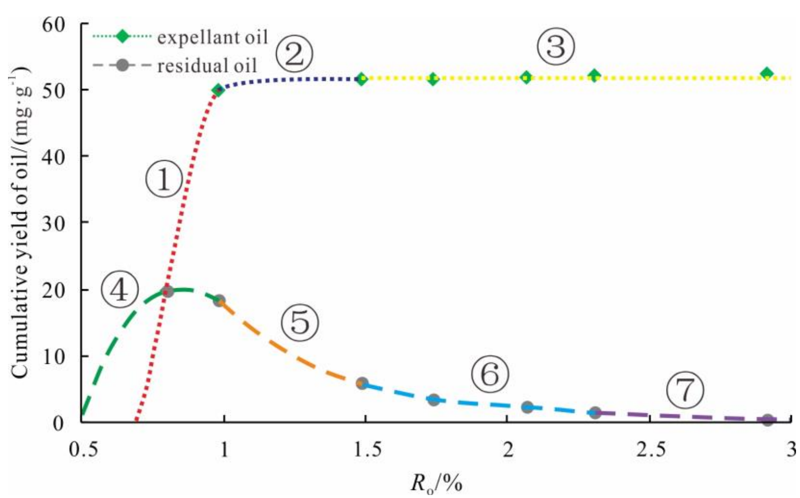
① $G(g)=11.8401\ln R_o+19.3581$ $(0.5\%\le R_o\le 1.0\%)$

② $G(g)=123.8148R_o^3-367.3351R_o^2+371.9816R_o-109.1679$ $(1.0\%<R_o\le 1.5\%)$

③ $G(g)=275.1661R_o^3-1594.3733R_o^2+3143.0558R_o-2013.7619$ $(1.5\%<R_o\le 2.3\%)$

④ $G(g)=16.6188R_o^3-175.2918R_o^2+621.3232R_o-574.8112$ $(2.3\%<R_o\le 3.0\%)$

G(g)-generated gas, mL/g; R_o-vitrinite reflectance, %



① $E(o)=-1733.753R_o^3+4199.6079R_o^2-3174.0208R_o+758.7985$ $(0.7\%\le R_o\le 1.0\%)$

② $E(o)=-0.0715R_o^3-2.7291R_o^2+9.1288R_o+44.3044$ $(1.0\%<R_o\le 1.5\%)$

③ $E(o)=51.6158$ $(R_o\ge 1.5\%)$

④ $R(o)=125.1029R_o^3-432.573R_o^2+463.5411R_o-138.2817$ $(0.5\%<R_o\le 1.0\%)$

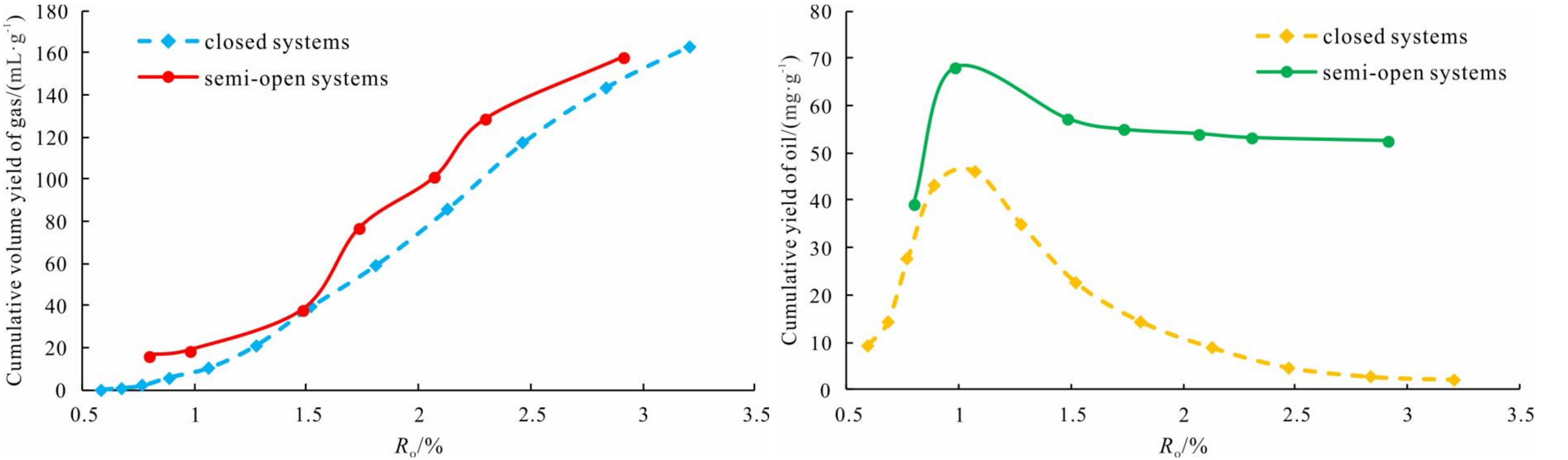
⑤ $R(o)=169.4485e^{-2.2716R_o}$ $(1.0\%\le R_o\le 1.5\%)$

⑥ $R(o)=-12.6326R_o^3+76.4612R_o^2-156.9692R_o+111.6618$ $(1.5\%<R_o\le 2.3\%)$

⑦ $R(o)=71.1596e^{-1.7062R_o}$ $(2.3\%<R_o\le 3.0\%)$

E(o)-expellant oil, mg/g; R(o)-residual oil, mg/g;
G(o)-generated oil=E(o)+R(o), mg/g; R_o-vitrinite reflectance, %

Results and discussion



Comparison of the cumulative volume yield of gas and the cumulative yield of oil between closed and semi-open systems

Compared with the thermal simulation experiment in closed system, in the semi-open system, the cumulative yield of oil is higher and closer to the actual geological conditions.