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Comprehensive evaluation of the geochemical characteristics of the hydrocarbon source rocks in Zhenjing block

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Hydrocarbon source rocks are developed in the Zhenjing block of Ordos basin. In order to better study the maturity of the hydrocarbon source, 99 samples were analyzed, and organic carbon was mainly classified in two intervals, one being less than 1% (25.5%), and the other ranging from 1% to 4% (55.56%). The ratio of hydrogen to oxygen was generally less than 0.86, and that of oxygen to carbon was less than 0.08. From the zones of Chang 9 to Chang 7, the type of organic matter gradually improves, being typically of mixed type. Up to the Chang 7 zone, source rocks and environmental conditions are getting worse, so is the organic matter type, dominantly controlled by humic kerogen. Through the study of the maturity of organic matter under the conditions of a maximum temperature of 443.5°C, we found that the minimum Ro was 0.57%, the maximum was 0.98%, and the average OEP was 1.28. TT and Ro showed that low mature stage of hydrocarbon source was characteristic of Yanan 2 zone, and the mature stage of hydrocarbon source was characteristic of Yanan 2 and 3 zones. The thermal evolution analysis indicates that the main hydrocarbon source was affected by tectonic thermal events and reached a hydrocarbon generation peak at the end of Cretaceous period.

Key words: Hydrocarbon source rocks, Geochemical characteristics, Kerogen, Thermal evolution.

INTRODUCTION

Ordos basin is a large continental sedimentary basin in the eastern part of China, and the Triassic Yanchang formation is a potential oil & gas reservoir in the area. Triassic Yanchang formation is characterized by hydrocarbon source rocks, integration of resource, reservoir and cap rocks, and potential reservoirs with wide area (Huang et al., 2009, Zhang et al., 2006). The Mesozoic oil and gas exploration in Zhenjing block began in the 1990s, and only a small oil-bearing area in the Chang 6 zone was found (Li X, Zhu Z, Feng C, et al., 2009). There has not been great breakthrough until 2006. Since then, with the discovery of ZJ5 well, the exploration upsurge in Chang 8 zone began. Successively there were many wells with high production, but the exploration rate was very low, because the geologists, who were restricted in the understanding of the geological background of this area (Sun Y, Liu C, Lin M, et al., 2009), could not distinctly assign the geological conditions and the law of the Mesozoic reservoirs and slowed down the procedure of exploration (Yang H, Fu J, Wei X, et al., 2008). So, the study of the geochemical characteristics of hydrocarbon source rocks in Zhenjing block should explain the relationships between reservoir and hydrocarbon source rocks, and provide theoretical basis for further research.

ABUNDANCE OF ORGANIC MATTER

There are 93 core samples of hydrocarbon source rocks, among them one sample from a ding zone and two samples from Zhi luo zone. Statistical results show that the organic carbon of core samples is generally less than 1.2% (accounting for 88.57%), and the majority of it is less than 1%, (accounting for 68.57%). However, the organic carbon of debris samples is generally greater than 1% and for most of them it is greater than 2%.

The organic carbon of the source rock is low (less than 0.5%) or high (greater than 10%) to generate and expulse hydrocarbon. The hydrocarbon content and the conversion ratio should be chosen as the primary indexes to evaluate organic matter and set up the standard suitable for this area. Inferred by tables 1 and 2: (1) organic matter in this area is mainly classified in two intervals, one being less than 1% (accounting for

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25.5%), and the other ranging from 1% to 4% (accounting for 55.56%). The minority of organic carbon ranges from 4% to 8% (accounting for 10%). A few scattered points are greater than 10% (accounting for 8.89%). Considering the characteristics of high carbon in this area, we plan to make the organic carbon of the conventional shale expand to 8%, although the organic carbon ranges from 8% to 10%. (In fact the cutoff of organic carbon in this area is 6%). (2) The properties of non-organic matter in this area are characterized by organic carbon less than 0.6% and hydrocarbon content less than 100 ppm and its conversion rate is less than 1. Therefore, we define the organic carbon of 0.6% as the cutoff of organic matter. (3) The shale with high carbon has strong absorbability, which is distributed in poor hydrocarbon source rock and non-hydrocarbon source rock, so generally there exists a positive relationship between hydrocarbon content and organic carbon, but its corresponding conversion rate is low. However, the conversion rate in different strata probably varies due to the difference of source and environmental conditions. Generally its conversion rate in Chang 7 zone is higher, and it can reach the poor or moderate class of hydrocarbon source rock. (4) The conversion rate in the area is generally lower than the common conversion rate. Therefore, organic carbon of 1% to 4% and hydrocarbon content of 800 ppm corresponds to a conversion rate ranging from 1% to 4%. Accordingly, hydrocarbon content higher than 1000 ppm corresponds to a conversion rate from 2% to 6%.

Through the above analysis we found that the abundance of organic matter of T_3y^2 section in Zhenjing block is better than of T_3y^3, and best in Chang 7 zone of T_3y^2 section, and worst of the Jurassic Yanan section (J_1y^2).

ORGANIC MATTER TYPE

Organic matter type is a quality evaluation indicator of hydrocarbon source rock. Generally the source rock conditions and sedimentary background determine the kerogen quality of hydrocarbon source rock (Durand, Bernard, 1980, Song D, He D, Wang S, 2013, Lu S, Chen F, Li J, et al., 2012)

Identification of micro-components of kerogen

Organic mineral mirror (transmission, reflection) is a statistical method for qualitative and semi-quantitative analysis. It is a simple, rapid method for evaluation of the type of organic matter, and is not affected by the thermal evolution of organic matter (Jansa et al., 1990, Xiuqin et al., 2008). The identification results show that under the microscope (Fig.1) Yanchang Formation mudstone kerogen and coal amorphous content are low and occasionally display dark fluorescence. The liptinite in each layer has a certain distribution, the content is relatively low, with large differences. Various macerals, such as sporinite, cutinite, dendrimer, etc. are yellow green, bright yellow, dark yellow fluorescent; vitrinite came from the xylem. Mudstone kerogen vitrinite did not fluoresce, coal rock desmocollinite shows dark brown fluorescence. Inertinite from higher plant xylem strongly carbonized or based on xylem gelation further on the carbonization. From the mudstone kerogen maceral triangle (Fig.1) it can be seen on the top and bottom that Yanchang formation was mainly mudstone kerogen in vitrinite and inertinite two components, in a few samples of liptinite and the amorphous content was higher, the type of organic matter was of basically humic type. The content of mudstone kerogen amorphous particles and liptinite was higher in Ch 4 to Ch 8 of Yanchang, organic matter types are mixed type partial sapropel, of which most Ch 7 samples showed sapropelic type or near sapropelic type.

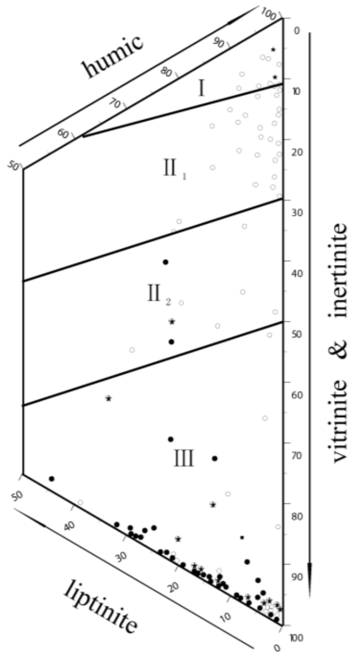

Fig. 1. Triangle of kerogen fractions in mudstone of Erdos basin.

Microscopically, identification of micro-components is an effective means of classifying kerogen types. The overall statistics of 28 microscopy samples is classified into three types, II_1 accounting for 39.29%, II_2 accounting for 50%, II_1 accounting for 10.71% (table 3).

Table 1. Statistics of hydrocarbon content from hydrocarbon source in Zhenjing area.

Horizon	Total number of Samples	Good hydrocarbon source rock (>1000ppm)		Moderate hydrocarbon source rock (200-1000ppm)		Inferior Hydrocarbon source rock (100-200ppm)		Non hydrocarbon source rock(<100ppm)		Proportion of Moderate to good hydrocarbon source rock (%)	Evaluation of hydrocarbon source rock
	Number	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)		
J_1y^2 y9+10	11			4	36.36	6	54.55	1	9.09	36.36	Inferior
T_3y^3 ch5	10			7	70	1	10	2	20	63.64	Moderate
ch6	30	1	3.33	7	23.33	10	33.38	12	40	25.81	Inferior
T_3y^2 ch7	18	5	27.78	6	33.33	5	27.78	2	11.11	61.11	Good
ch8	11			6	54.55	4	36.36	1	9.09	50	Moderate
ch9	5			4	80			1	20	80	Moderate
T_3y^1 ch10	2			1	50	1	50			poor representation	Inferior
Total	87	6	6.9	35	40.23	27	31.03	19	21.84		

Table 2. Organic matter conversion rate of hydrocarbon source rock in Zhenjing area.

Horizon	Total number of samples	Good hydrocarbon source rock HC/C (>4%)		Moderate hydrocarbon source rock HC/C (2-4%)		Inferior Hydrocarbon source rock HC/C (1-2%)		Non hydrocarbon source HC/C (<1%)		Proportion of Moderate to good hydrocarbon source rock (%)	Evaluation of hydrocarbon source rock
	Number	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)		
J_1y^2 y9+10	11					7	63.64	4	36.36	0	Inferior
T_3y^3 ch5	10					2	20	8	80	0	Inferior
ch6	30	2	6.67	1	3.33	11	36.67	16	53.33	10	Inferior
T_3y^2 ch7	18	3	16.67	8	44.44	5	27.78	2	11.11	61.11	Good
ch8	11			1	9.09	7	63.64	3	27.27	9.09	Inferior
ch9	5			1	20	4	80			20	Moderate
T_3y^1 ch10	2			1	50			1	50	poor representation	Inferior
Total	87	5	5.75	12	13.79	36	41.38	34	39.08		

Table 3. Statistics of organic matter type of Mesozoic source rock in Zhenjing area.

Hydrocarbon source rock / Horizon	Humic (%)	Liptinite (%)	Vitrinite (%)	Inertinite (%)	TI	Organic matter type
Ch7	28.2-72.1	4.26-44.39	3.85-50.84	0.19-18.09	-24.67-15.05	II_2
Ch8	32.85-63.35	9.95-19.19	26.7-47.09	0.87	6.25-48.3	II_2, II_1
Ch9	10.33-36.29	12.27-17.0	50.57-72.04	0.61-8.86	-35.8-3.66	II_2-III

Table 4. Elemental analysis of Kerogen of Mesozoic in Zhenjing area.

Ratios / Horizon	H/C (KTI on Average)	O/C (KTI on Average)	KTI (KTI on Average)	Organic matter type
Ch6	0.560-0.984(0.755)	0.04-0.139(0.067)	22.98-58.2(39.21)	III_1 main type II secondary
Ch7	0.589-1.190(0.859)	0.038-0.100(0.059)	24.6-70.77(44.85)	II main type III_1 secondary
Ch8	0.600-0.790(0.726)	0.07-0.120(0.093)	23.73-40.9(34.16)	II-III_1
Ch9	0.674-0.875(0.771)	0.06-0.091(0.072)	35.22-49.53(42.98)	II_1-II

Kerogen elemental analysis

Extension of coal group and analysis results of mudstone kerogen elements in Yanan group of Mesozoic in the Basin are displayed in Fig.2. Terrestrial plant debris being the main organic matter of Jurassic mudstone kerogen and coal elemental composition being very close, 29 mudstone kerogen samples and two coal samples were of humic type; the top of Yanchang Formation Ch 1 - 3 and the bottom of Ch 10 shale kerogen, in addition to Fu 2 well Ch 3 and low 2 well Ch10 two samples at the bottom of the distribution, unable to determine the original source material type, while the other 8 samples were of humic type; analysis of 31 samples in Yanchang Formation Ch 9 – Ch 4+5, the Ch 7 of 14 samples, 6 samples in a type II kerogen intervals, in the initial section II type track for the Jiefang 674 wells and two Tong chuan low mature kerogen samples (Ro = 0.65%, 0.54%), Mixed type of parent material reflects the western basin and the southern edge of the source rock for the partial sapropelic. It was also proved that the central basin is rich in algae and other aquatic organisms – semi-deep lake faces mudstone kerogen. In addition, the 17 Ch 7 samples were outside, 5 samples are distributed in type II kerogen interval, 12 samples are distributed in type III kerogen interval.

For the 67 samples collected in this study, the results of kerogen elemental analysis showed that the atomic ratio of hydrogen to carbon is commonly less than 0.86 and the atomic ratio of oxygen to carbon is less than 0.08. The samples data fall between II and III area of the plot (Fig 3). From tables 3 and 4 we knew that organic matter type is gradually getting better from Chang 9 zone to Chang 7 zone, and is dominated by mixed type. Up Chang 7 zone, since the source and environmental conditions are getting worse, organic matter type is getting poor, mainly characteristic of humic kerogen type.

THE ORGANIC MATTER MATURITY

Organic matter maturity is an important aspect of hydrocarbon source rock evaluation (Zhang T, Ellis G S, Ruppel S C, et al., 2012, Sun X, Zhang T, Milliken K L, 2014, Marynowski L, Salamon M, Narkiewicz M, 2012). According to the theory of kerogen pyrolysis oil, it is generally believed that temperature and burial time restrain the evolution of organic matter when the vitrinite reflectance of hydrocarbon source rock is equal to or higher than 0.5%. In this case, the odd-even predominance value of n-paraffin is gradually dropping down to 1. When the maximum pyrolysis temperature is higher than 435°C, then the mature stage is to form.

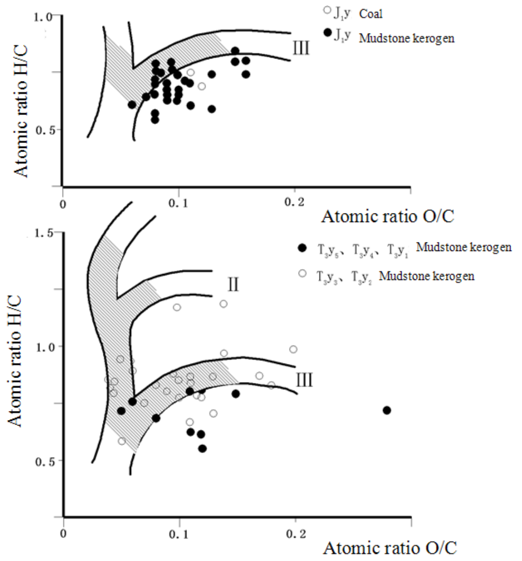

Fig. 2. Elemental map coordinates of mudstone kerogen in the basin.

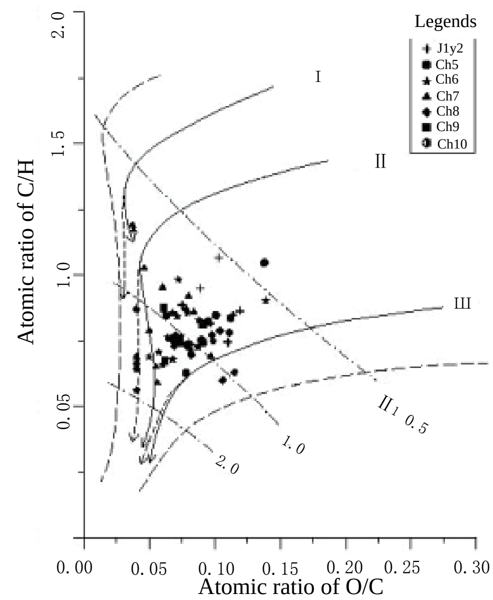

Fig. 3. Mesozoic kerogen type in Zhenjing area.

Vitrinite reflectance

Among the Ro values of 31 samples, the minimum is 0.57%, and the maximum is 0.98%. The Ro in Zheng block is consistent with the Ro in Jing block. The Ro value of hydrocarbon source rock in the J_1y^2 section is commonly from 0.57% to 0.67%, and the average value of 0.62% is less than 0.7%, so the mature source rock is a low one.

The Ro value of hydrocarbon source rock in the T_3y^3 section ranges from 0.60% to 0.98%, averagely 0.75%. The values are less than 0.7% accounting for 40%. All properties indicate that the hydrocarbon source rock in T_3y^3 section belongs to the low mature and mature one.

The Ro value of hydrocarbon source rock in the T_3y^2 section is greater than 0.7%, ranging from 0.7% to 0.89%, averagely 0.78%. Therefore these parameters show that the hydrocarbon source rock in T_3y^2 section belongs to mature one.

According to the Ro and coal rank analysis, the degree of the evolution of the hydrocarbon source rocks in Yan and Chang zones is reducing from Qingyang east to its surroundings. The Zheng-Jing blocks are located in the west basin of the thermal evolution band. In the south of Qingyang - Fuxian and North of Zhengning - Yijun, the Ro value in T_3y^{2+3} sections generally ranges from 0.7% to 1.0%. For example, in Tong Chuan county, the Ro value of An 1 well in T_3y^2 section, is 0.7%, and 1.0% of Xiang 1 well and 0.8% of Qing 36 well. Determined from coal field data, the metamorphic center of Wayaobao coal series in T_3y^5 sections exists in Huanglingdian area, in which a lot of coal abundant with gas and with a large degree of metamorphism was explored. From Huangshen 1 well to Tongchuan area, the Ro value of 0.918% gradually decreases to 0.695%.

As above said, hydrocarbon source rocks of Yan- Chang zones buried or exposed to surface have entered the mature stage. By contrast, the evolution degree of Chang zones is higher and reaches the mature stage. However, the mature stage of Yanan zones is low, belonging to low mature source rock.

Maximum peak temperature of rock pyrolysis

The pyrolysis peak temperature of hydrocarbon source rock in Yanan No.2 section is from 430°C to 439°C, with an average of 433.7°C, and it reflects non-mature and low mature characteristics. The pyrolysis peak temperature in Yanan No.3 section is 439°C - 459°C, individually reaching 473°C, averagely 449°C. In Yanan No.2 section the lowest peak pyrolysis temperature is 437°C, and the highest is 455°C, commonly between 440 - 450°C, with an average of 443.5°C. According to the standard pyrolysis peak temperature, all in Yanan No.2 and No.3 belong to mature hydrocarbon source rock.

Odd-even predominance value of n-paraffin

The distribution of OEP value is not obvious in different characteristics strata, but it clearly reflects the maturity in the different strata (Guo J, Fang J, Cao J, 2012). Generally in the Yanan zone of Jurassic, OEP value is approximately from 1.15 to 1.44, much more than 1.30, the average of 1.28, and the characteristics show low maturity. In Yanchang No.3 section of Triassic, the minimum of OEP is 0.97, and the maximum is 1.60, much less than 1.30, with an average of 1.193. In Yanchang No.2 section of Triassic, the OEP value is from 1.03 to 1.28, with an average of 1.107. According to the OEP classification standard, the Triassic hydrocarbon source rock has met a mature stage.

Time - temperature index (TTI)

Based on the burial history and TTI value of Zhentan 2 well and Jingtan 2 well, it is inferred that the Yanan bottom of Jurassic in Zhenjing block could be at the maximum depth of 1700 m in Cretaceous era, along with the paleo temperature of 67.5°C. The current TTI value is from 8.1641 to 8.5168, equivalently the converted Ro value is 0.58%. By a similar method, the buried depth of the Yanchang No.2 section of Triassic could be at 2300 m in the early Cretaceous, along with the paleo temperature of 82°C - 86°C. The current TTI value is 23.8333 in Jingchuan block and 32.5677 in Zhengyuan block. Equivalently the converted Ro value is from 0.73 to 0.73.

Thermal evolution shows that the hydrocarbon source rock of Yanan No.2 section belongs to the low mature stage of thermal evolution. The hydrocarbon source rock of Yanchang No.2 and 3 has reached its mature stage of thermal evolution. Overall evolution degree is consistent with the Ro values.

THERMAL EVOLUTION ANALYSIS OF HYDROCARBON SOURCE ROCK

To facilitate the thermal evolution analysis of hydrocarbon source rock, we made the burial evolution chart of Zhengtan 2, Jingtan 2 and Qing 36 wells according to the drilling data and adjacent borehole formation data. On the basis of the above formation temperature data, the paleo temperature and its gradient of each structural layer were calculated using the compensation coefficient method. Subsequently the TTI value of the thermal evolution process was obtained. By comparing TTI with Ro we consider the results as basically reliable.

According to the burial history (Fig 4) and TTI value, the oil threshold time of hydrocarbon source rock in Yanchang No.2 and 3 sections roughly matches the evolution degree time. For example, comparing the oil and gas evolution with its corresponding zones of Zhengtan 2 well, burial history shows that the oil threshold time of the main hydrocarbon source rock in Yanchang No.2 section is earlier than in Yanchang No.3 section, and namely late Jurassic and early Cretaceous (approximate 142Ma) or early Cretaceous (approximate 131Ma). The main hydrocarbon source rock influenced by tectonic thermal events has entered the hydrocarbon generation peak at the end of early Cretaceous, other part of the rock probably later.

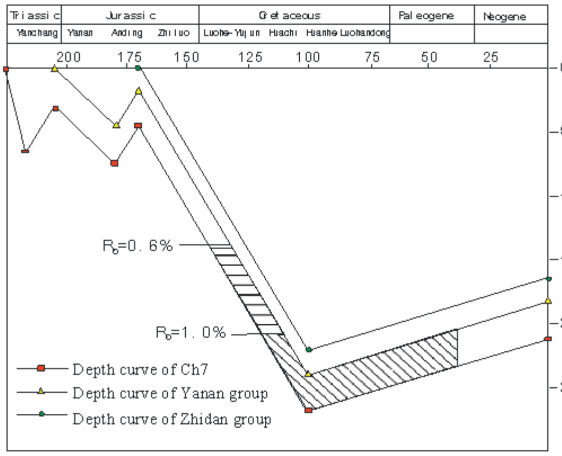

Fig. 4. The burial history of well HongHe 1

COMPREHENSIVE EVALUATIONS ON THE HYDROCARBON SOURCE ROCK

According to the characteristic analysis of the hydrocarbon source rock above, it is inferred that hydrocarbon source rock mainly exists in Chang 7 section. According to the shale thickness distribution in Chang 7 section, we knew that the thicker shale expands to the north and north-east, the thickness ranging from 20 m to 100 m, and the center of hydrocarbon generation and hydrocarbon supply is located in north-east in the studied area.

In Zhenjing block, the hydrocarbon source rock of T_3y^3 is relatively good, the best in Chang 7 zone, better in T_3y^2, the worst in J_2y^2. The oil threshold time of hydrocarbon source rock in Yanchang No.2 and 3 sections roughly matches the evolution degree time. The oil threshold time of the main hydrocarbon source rock in Yanchang No.2 section began in the late Jurassic and early Cretaceous (approximate 142Ma). And the oil threshold time in Yanchang No.3 section was in the early Cretaceous (approximate 131Ma). The hydrocarbon generation of the main hydrocarbon source rock in this area reaches the peak in Paleozoic (33Ma - 43Ma), in south-west probably later. It explains the peak period in this area up to now. Obviously it is later than the main oil region of Ordos basin in early Cretaceous.

CONCLUSION

(1) The hydrocarbon source rock of J_2y^2 is low mature. The hydrocarbon source rock in T_3y^3 is low and mature. The hydrocarbon source rock in T_3y^2 is mature.

(2) The hydrocarbon source rock of Yan-Chang zones buried or exposed to surface has entered the mature stage. By contrast, the evolution degree of Chang zones is higher and has reached the mature stage. However, the mature stage of Yanan zones is low, belonging to low mature source rock.

(3) The hydrocarbon generation of the main hydrocarbon source rock in this area reached the peak in Paleozoic (33Ma - 43Ma), in south-west probably later. It explains the peak period in this area up to now. Obviously it is later than the main oil region of Ordos basin in early Cretaceous.

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ПОДРОБНА ОЦЕНКА НА ГЕОХИМИЧНИТЕ ХАРАКТЕРИСТИКИ НА НЕФТОНОСНИ СКАЛИ В БЛОКА ЖЕНДЖИНГ

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(Резюме)

Известни са нефтоносни скали в блока Женджинг в басейна Ордос. Анализирани са 99 проби от тях. Установено е, че органичният въглерод е разпределен главно в два интервала – единия под 1% (25.5%), а другия - от 1% to до 4% (55.56%). Отношението на водорода към кислорода е главно под 0.86, а на кислорода към въглерода е под 0.08. Видът на органичната материя постепенно се подобрява от зоната Chang 9 до Chang 7с характеристики от среден тип. В зоните под Chang 7 нефтоносните скали и природните условия се влошават, така че органичната материя е главно от хуминовкероген. Внимателното изследване на възрастта на органичната материя при максимална температура443.5°C показва, че Ro е 0.57%, а максималнатастойност е 0.98%. Средната OEP е 1.28. Времево-температурният индекс TT и Ro показват, че въглеводородните компоненти отговарят на характеристиките в зоната Янан 2, а степента на зрялост на въглеводородния източник отговаря на зоните Янан 2 и 3. Термичният еволюционен анализ показва, че главният въглеводороден източник е повлиян от тектонични термични процеси и достига връх в образуването на въглеводороди в края на периода Креда.