Characteristics of the Lower Cambrian Yuertus Formation source rocks in the Tarim Basin, NW China

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Abstract. In this paper, the distribution of source rocks of the lower Cambrian Yuertus Formation in the Tarim Basin is analyzed, a series of organic geochemical characteristics are tested, the characteristics of the source rocks are analyzed, and the thermal evolution and hydrocarbon generation history of the source rocks are simulated. The results show that the distribution of the source rocks is obviously controlled by sedimentary facies; the source rocks are sapropelic organic matter with high abundance and have reached the stage of mature-overmature thermal evolution; those in the eastern depression area have reached the peak of oil generation in the middle Caledonian period, the peak of gas generation in the middle Hercynian period and the end of hydrocarbon generation in the late Hercynian period. In the western uplift area, the source rocks entered the peak of oil generation during late Hercynian period, then entered the stage of gas generation in the early Indosinian period, and then stopped hydrocarbon generation due to uplift and denudation.

1. General situation of basin (Regional geological background)
The Tarim Basin is one of the typical basins with marine source rocks in China. The exploration area of the Tarim Basin is about $56 \times 10^4 \text{km}^2$. Paleozoic marine oil and gas resources are abundant in the basin. Large oil and gas fields such as Halahatang Oilfield, Lungudong Gasfield and Tahe Oil and Gas Field have been found in the Tabei Uplift, and Hotan River Gas Field, Bird Mountain Gas Reservoir and Yubei 1 Oil Field have been found in the Bachu Uplift-Makit Slope Zone. It is thought that the oil and gas are all related to Cambrian source rocks. (Zhao Mengjun, 2002; Guo Jianjun, et al., 2007; Jin Zhijun, et al., 2017). Because of the deep burial of Cambrian source rocks in the basin, only Xinghuo 1 well drilled in the northwest of Shaya uplift encountered Cambrian source rocks. For marine source rocks in the Tarim Basin, predecessors have done a lot of research on the basis of outcrop source rocks (Liang Digang, et al., 2000; Zhang Shuichang, et al., 2001).

The Tarim Basin lies between the South Tianshan Mountains and the West Kunlun Mountains. The southeastern side of the Tarim Basin is limited by the Altun fault zone. It is a large superimposed composite basin developed on the pre-Sinian continental crust basement (Xu Zhiqin, et al., 2011; Yu Bingsong, et al., 2011). The basin evolution experienced two tectonic periods: Caledonian-Hercynian Craton and Indosinian-Himalayan foreland basin (Du Jinhui, et al., 2016). The development of the Lower Cambrian Yuertus Formation in the Tarim Basin shows distinct characteristics of East-West differentiation: a set of undercompensated basin facies shale deposits in the east, black organic shale in the lower Cambrian, and a set of open platform and limited platform facies carbonate platform deposits in the West (Fig.1). The Lower Cambrian Yuertus Formation around the basin mainly occurs in Altun Mountains in the southeastern margin, Kuruktag in the...
northeastern margin, West Kunlun Mountains in the southwestern margin, Keping-Aksu in the northwestern margin and South Tianshan in the northern margin.

Figure 1. Sedimentary facies map of the Lower Cambrian Yuertus Formation in the Tarim Basin

Figure 2. Isotropic maps of source rocks of the Lower Cambrian Yuertus Formation in the Tarim Basin (Revised from Xiong Ran, et al. 2015)

2. Distribution and Characteristics of Source Rocks of Yuertus Formation

2.1 Distribution of source rocks

The Mesozoic-Paleozoic in the Tarim Basin is characterized by multi-layered source rocks, of which the Lower Cambrian Yuertus Formation (Є1y) marine mudstone is a proven high-quality source rock (Zhu Chuanling, et al., 2014; Zhu Guangyou, et al., 2016) formed in the sedimentary environment of the under-compensated basin, mainly black mudstone and thin-beded mudstone with horizontal texture and rich organic matter. The mudstone is widely distributed in the sags of the basin with the thickness of 30~50m in the Manjiaer Sag in the eastern part of the basin and Awat Sag in the western part of the basin, while with the thickness of less than 15m in the Tangguzibas Sag in the south of the
basin and the Yecheng Sag in the southwest (Fig. 2). The Well Xinghuo 1 in the Saya Uplift has the thickness of 31m (Zhu Chuanling, et al., 2014). The Yuertus Formation was also outcropped in the Yuertus Mountain of Wushi area, Kungaikuotan and Sugaitebulake of Akesu area, and the thickness is generally less than 10m.

2.2 Characteristics of source rocks

2.2.1 Characteristics of Organic Matter Abundance

The Lower Cambrian Yuertus Formation is extremely rich in organic matter, and is a set of high-quality marine argillaceous source rocks. According to the analysis results of 7 mudstone samples from outcrops of Qukquart and Sugate burak in the Aksu area, the total organic carbon content (TOC) ranges from 0.38% to 11.00% (Table 1), with an average of 5.93%. However, after a long and multi-stage thermal evolution, the current content of chloroform asphalt “A” of the source rocks is only 0.0005%~0.0094%, with an average of 0.0041%. Rock-eval pyrolysis analysis also shows that the free hydrocarbon content is 0.03~0.09 mg/g and the pyrolysis hydrocarbon content is 0.05~1.48 mg/g. The pyrolysis hydrocarbon potential is at most 1.54 mg/g, but most of them are only distributed between 0.11 and 0.23 mg/g. Hydrogen index and hydrocarbon index are also very low. Therefore, the hydrocarbon generation potential of Yuertus Formation source rocks is very low.

Table 1. Table of Organic Matter Abundance and Maturity Parameters of Yuertus Formation Source Rocks

| Sample number | Stratigraphic horizon | lithology     | TOC  | "A"  | VRo  | Tmax | S1    | S2    | S1+S2 | Ih   | Inc  |
|---------------|----------------------|---------------|------|------|------|------|-------|-------|-------|------|------|
| SGT-1         | Є1.y                 | Black shale   | 9.67 | 0.0045 | 1.061 | 455  | 0.09  | 0.69  | 0.78  | 7.14 | 0.93 |
| S001          | Є1.y                 | Black shale   | 5.86 | 0.0005 | 0.931 | 540  | 0.03  | 0.09  | 0.12  | 1.54 | 0.51 |
| S002          | Є1.y                 | Black shale   | 1.43 | 0.0086 |      | 428  | 0.03  | 0.20  | 0.23  | 13.99 | 2.10 |
| S003          | Є1.y                 | Black shale   | 6.09 | 0.0026 | 0.953 | 436  | 0.04  | 0.11  | 0.15  | 1.81 | 0.66 |
| S004          | Є1.y                 | Black shale   | 7.08 | 0.0021 |      | 476  | 0.03  | 0.09  | 0.12  | 1.27 | 0.42 |
| S005          | Є1.y                 | Black shale   | 11.0 | 0.0094 | 0.878 | 439  | 0.06  | 1.48  | 1.54  | 13.45 | 0.55 |
| S006          | Є1.y                 | Black shale   | 0.38 | 0.0015 |      | 475  | 0.06  | 0.11  | 13.26 | 15.92 |      |

Figure 3. Gas chromatogram of chloroform asphalt "A" saturated hydrocarbons in source rocks of Yuertus Formation

2.2.2 Characteristics of Organic Matter Types

The distribution of n-alkanes is mainly nC14~nC38, dominated by low molecular weight n-alkanes (Fig. 3). The main peak carbon is mainly nC17, nC21/nC22 values range from 1.35~5.48, and the isoprene-like alkanes has a phytanane advantage. The Pr/Ph values range from 0.66~0.97 (Table 2). The tricyclic terpenoids have C25 dominance and is characterized by C20<C21<C23 distribution (Fig. 4). The C21/C23 tricyclic terpane ratio is between 0.39 and 0.83. The content of gammacerane is...
relatively low, and the gammacerane/αβC\textsubscript{30} hopane values are 0.16~0.39, indicating a normal salinity conditions of the sea water. The regular sterane abundance of the source rocks has the characteristics of C\textsubscript{27}>C\textsubscript{28}<C\textsubscript{29}, the distribution of C\textsubscript{27} (20R), C\textsubscript{28} (20R), C\textsubscript{29} (20R) is "V" type (Fig. 4). It indicates that the argillaceous source rocks of the Yuertus Formation are formed in a marine-reduction environment with a certain salinity, and the original organic matter is derived from algae. Its organic matter type is sapropelic.

![Figure 4](image)

**Figure 4.** Gas Chromatography-Mass Spectrometry of Saturated Hydrocarbon in Rong1y Source Rock of Aksu Sugai Bulak Section

**Table 2.** Biomarker Parameters Table of Yuertus Formation Source Rocks

| Sample number | Stratigraphic horizon | lithology   | nC\textsubscript{max} | nC\textsubscript{23}/nC\textsubscript{22}+ | Pr/Ph | Pr/nC\textsubscript{17} | Ph/nC\textsubscript{18} | C\textsubscript{20}/C\textsubscript{25}TT | C\textsubscript{29}/C\textsubscript{30}H | G/αβC\textsubscript{30} |
|---------------|-----------------------|-------------|------------------------|------------------------------------------|-------|------------------------|------------------------|-------------------------------|-------------------------------|----------------------|
| SGT-1         | C\textsubscript{16}y   | Black shale | C\textsubscript{17}    | 1.78                                     | 0.81  | 0.40                   | 0.81                   | 0.48                          | 0.49                          | 0.21                 |
| S001          | C\textsubscript{16}y   | Black shale | C\textsubscript{17}    | 4.87                                     | 0.78  | 0.10                   | 0.78                   | 0.41                          | 0.55                          | 0.12                 |
| S002          | C\textsubscript{16}y   | Black shale | C\textsubscript{17}    | 1.81                                     | 0.79  | 0.36                   | 0.52                   | 0.83                          | 0.60                          | 0.16                 |
| S003          | C\textsubscript{16}y   | Black shale | C\textsubscript{17}    | 0.85                                     | 0.66  | 0.37                   | 0.59                   | 0.68                          | 0.58                          | 0.16                 |
| S004          | C\textsubscript{16}y   | Black shale | C\textsubscript{16}    | 5.48                                     | 0.97  | 0.23                   | 0.35                   | 0.62                          | 0.52                          | 0.18                 |
| S005          | C\textsubscript{16}y   | Black shale | C\textsubscript{17}    | 2.06                                     | 0.78  | 0.35                   | 0.51                   | 0.39                          | 0.52                          | 0.19                 |
| S006          | C\textsubscript{16}y   | Black shale | C\textsubscript{18}    | 2.75                                     | 0.96  | 0.42                   | 0.39                   |                               |                               |                      |

2.2.3 Maturity Characteristics of Organic Matter in Source Rocks

The source rocks of the Yuertuos Formation in the Well Fang 1 of the Bachu Uplift have the current Ro values of about 2.0%. The vitrinite-like reflectance values of the Yuertus Formation source rocks in the outcrops of Quququart and Sugate burak in the northwest of the basin is only 0.878%~1.061%, and the Tmax values are only 428~476°C except for a value of 540°C. The reflectance values calculated by dimethylnaphthalene and trimethylnaphthalene series compounds are 1.81% and 1.55%, respectively, indicating the thermal evolution of the Lower Cambrian Yuertus Formation organic matter in the western basin is generally at a high maturity stage. In the central part of the basin, such as Tazhong, Tabei and Tadong areas, the thermal evolution of the Lower Cambrian Yuertus Formation organic matter is generally highly mature to over-mature (Wang Feiyu, et al., 2003).

3. Hydrocarbon Generation History of Thermal Evolution of Organic Matter in Source Rocks

The Tarim Basin is a large “cold basin” with low geothermal flow values. However, the geothermal flow values are significantly different in different tectonic units in different geological ages, which has the that the geothermal flow values of the Paleozoic are higher than those of the Mesozoic, and the values of the Mesozoic are higher than those of the Cenozoic, and the values of the depression area are higher than those of the uplift area (Wang jun, et al., 1995). Basin simulation shows that the organic matter of the source rocks of the lower Cambrian Yuertus Formation mostly entered the peak of oil generation in the middle and late Caledonian period. In the southwestern part of the basin, the thermal evolution was stagnant due to the uplift and denudation of the late Caledonian period. In the middle-late period of the Hercynian, the thermal maturity of organic matter entered the peak of oil generation.

![Image of gas chromatogram](image)
again, and in the early Indosinian period it entered the stage of gas generation, and then ceased for uplift and denudation (Fig. 5a). In the Manjar depression in the eastern part of the basin, gas generation began in the late Caledonian period, then reached its peak in the Early-Middle Hercynian period, and ended in the late Hercynian period (Fig. 5b).

**Figure 5.** A Simulated Map of Hydrocarbon Generation History of Thermal Evolution of Lower Cambrian Yuertus Formation Source Rocks in Tarim Basin

4. Conclusion

4.1 The distribution of source rocks in the Lower Cambrian Yuertus Formation in the Tarim Basin is controlled by sedimentary facies and has obvious zonation, mainly distributed in the eastern part of the basin.

4.2 Organic carbon content, chloroform asphalt "A" content, pyrolysis studies on hydrocarbon potential index and organic geochemical characteristics show that organic matter in source rocks of Lower Cambrian Yuertus Formation in Tarim Basin is high abundance, a set of high quality source rocks is sapropelic type, and is in the stage of high-maturity-over-maturity thermal evolution.

4.3 The organic matter of the source rocks of the lower Cambrian Yuertus Formation mostly reached the peak of oil generation in the middle and late Caledonian. In the Western uplift area of the basin, the middle-late Hercynian period entered the peak of oil generation again, and the early Indosinian period entered the stage of gas generation, and then stopped hydrocarbon generation because of long-term uplift and denudation. Gas generation began in late Caledonian period in the basin depression area, peaked in Early-Middle Hercynian period, and ended in late Hercynian period.

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