Characterization of the import of *Botryococcus* to the source rocks of the upper member of the Lower Ganchaigou Formation in the Yingxi area, Qaidam basin, China

Li Xu\(^a\), Lantian Xing\(^b\)*

\(^a\) Northwest Branch, PetroChina Research Institute of Petroleum Exploration and Development, Lanzhou 730000, PR China.
\(^b\) Northwest Institute of Eco-Environment and Resources, Chinese Academy of Science, Lanzhou 730000, China.

*Corresponding author’s e-mail address: lantxing@163.com

**Abstract:** Substantial quantities of *Botryococcus* fossils have been detected in the source rocks of the upper member of the Lower Ganchaigou Formation in the Yingxi area, Qaidam basin, China. Dicyclic terpane biomarkers, predominantly drimanes or homodrimanes with the same characteristics, also have been detected in extracts from the source rocks. These salient features confirm that *Botryococcus* is an important parent material for the high-quality source rocks of the upper member of the Lower Ganchaigou Formation of the western Qaidam basin. Our findings contribute to a better understanding on this source rock series and its mechanisms of hydrocarbon generation.

**Keywords:** *Botryococcus*; Biomarker; Dicyclic terpane; Saline lacustrine source rocks; Yingxi area of the Qaidam basin

1. **Introduction**

The Qaidam basin on the northeastern Tibetan plateau is the highest lacustrine basin in China. The upper member of the Lower Ganchaigou Formation (E\(_3\)\(^2\)) in the western Qaidam basin hosts a saline lacustrine source rock series. This source rock series features high salinities (15-60‰), high carbonate contents (>20%), low total organic carbon (TOC) contents (0.4-1.0%), high hydrocarbon (HC) conversion values (with general “A”/TOC values of 20% and a maximum of 60%; and HC/TOC values of 12%, with a maximum of 40%), and it generates mass immature oil and gas (Peng, et al. 2004; Zhou et al., 2002). The hydrocarbon-generating mechanism of this source rock series is attributed to its special parent materials and sedimentary environments; however, at present, the types of hydrocarbon-generating parent materials are not clearly understood, which hinders an in-depth understanding of the hydrocarbon-generating mechanism of this source rock series. In this paper, we performed detailed micropaleontological and organic geochemical analyses on high-quality source rock samples collected from E\(_3\)\(^2\) in the study area and identified evidence for the import of hydrocarbon-generating materials into the source rocks. Our findings offer valuable data to support further investigations of the hydrocarbon-generating mechanisms of this source rock series.

2. **Samples and experiment**

The source rock samples used in our study were from the Yingxi area of the western Qaidam basin, the depocenter of E\(_3\)\(^2\). The sampling wells, drilled in 2018, were Shi41-2, Shi49-1, and Shi38-4. The
The coring site was the V Formation in the E2, which contains high-quality source rocks. The source rock samples are composed of limestone-bearing mudstone. Our study included micropaleontological analyses of 35 samples and gas chromatography-mass spectrometry (GC-MS) experimental analyses of 8 source rock samples.

The micropaleontological analyses mainly followed palynological methods. First, the source rock samples were coarsely crushed to approximately 0.5 mm in size, substantially macerated in HCl and HF and heated with 10% HCl for approximately 30 min. After the reaction was complete, 10% HF was added and the mixture was further stirred. When the reaction eased, the mixture was again treated with HCl. Then, distilled water was added and the mixture was separated multiple times using a centrifuge to remove clay and reaction residues. Finally, the isobaric solution (HI + KI + Zn) at 2.0 g/ml was used for flotation. The products obtained by flotation were transferred onto slides. The organic matter fractions and microfossil types were analyzed and measured with transmitted light and fluorescence under a binocular biomicroscope.

Saturated hydrocarbon fractions of the source rock samples were subjected to GC-MS analysis. The samples were crushed to 100-mesh and extracted by the Soxhlet method for 72 h. After the asphaltene in the chloroform bitumen “A” was precipitated with n-hexane, the saturated hydrocarbon fractions were separated. Analyses of the saturated hydrocarbon fractions were then conducted using a gas chromatography-mass spectrometer (GC-MS, Agilent technologies, USA). The MS used was 5973N, with an ion source temperature of 250°C and an ionization voltage of 70 eV. The GC used was 6890N, with a HP-5MS chromatographic column (30 m × 0.25 mm) and a 0.25 µm stationary-phase coating thickness. The carrier gas was high-purity helium. The starting temperature was 80°C, which was increased to 290°C at 4 °C/min. Then, the temperature was kept constant for 30 min.

3. Results and discussion
3.1 Microstructure of the source rocks

We analyzed the detrital components and the microalgal fossils in the organic matter of the source rocks. The results indicate that sapropelites are the main contributor to the microstructure of the source rocks in the study area and have a maximum content of up to 97% and an average content of 58%. High contents of algae, acritarchs and amorphous organic detritus were found in the sapropelites, with a small amount of exinites and inertinites. Generally, there are low amounts of vitrinites. The high sapropelite and exinite contents in the source rocks of the study area demonstrate that the samples have good oil-generating potential and are high-quality oil-prone source rocks.

Using detailed microscopic observations of the extracted organic detritus, several of the samples were found to be rich in algal fossils (Fig. 1). However, the alga types are relatively monotonous and were mainly comprised of Botryococcus and acritarchs, with Botryococcus accounting for a maximum of 30% of the total organic detritus. The Botryococcus samples occur in various forms, primarily as crumbs 10-20 µm in size. The group size generally ranges from 30 × 40 µm to 60 × 80 µm, with a maximum diameter of over 100 µm. Under natural-light microscopy, these algae were brownish yellow or light brownish yellow (Fig. 1A, B). Under blue light-excited fluorescence microscopy, the algae displayed a strong yellow fluorescence (Fig. 1a, b). Furthermore, we also noted high contents of algal amorphous organic matter on the circumference of the Botryococcus in the samples. Under reflection fluorescence microscopy, many amorphous kerogens appeared to be composed of Botryococcus or to include undegraded or incompletely degraded Botryococcus, which all displayed a strong yellow or yellowish-brown fluorescence. These observations indicate that Botryococcus is an important parent material for these source rocks. Zhou et al. (2002) also detected Botryococcus in Tertiary source rock samples from the Qaidam basin, which further supports our discoveries. Indeed, Botryococcus is widely developed in the Meso-Cenozoic strata in oil and gas bearing areas in China (Li, et al. 1992; Wan et al., 1999; He et al., 2004; Ji, et al. 2008); this material is directly associated with the development of source rocks. Botryococcus-containing rocks are important hydrocarbon-generating materials for Meso-Cenozoic continental oil and gas resources in China.
We also identified several acritarchs alginites, which generally account for less than 10% of the total organic detritus. These acritarchs alginites are round and have a light brown and yellow color that is almost transparent in natural light (Fig. 1C). Under blue light excitation, the organic skeletons displayed a distinct yellow fluorescence (Fig. 1c). It was difficult to categorize the acritarchs alginites into specific genera and phyla because they lacked detailed surface ornamentation; therefore, we categorized these organisms as acritarchs of algae.

3.2 Characteristics of biomarkers
Relative abundances of the biomarker parameters C$_{27}$aaa(20R) sterane, C$_{28}$aaa(20R) sterane, and C$_{29}$aaa(20R) sterane in source rocks can indicate the parent material sources of organic matter (Fu and Sheng, 1991; Duan et al., 2008). The C$_{27}$aaa(20R) sterane content in the source rocks of the study area ranges from 35% to 55%, with an average of 44%. The samples display a relatively high C$_{27}$aaa(20R) sterane dominance. Fig. 2A shows that the parent material of the samples mainly consists of aquatic algae. Moreover, the ratio of C$_{27}$aaa(20R) sterane/C$_{28}$ sterane in the samples is 0.27-1.35 and the ratio
of C_{29}ααα(20R) sterane/C_{27} sterane is 0.20-0.72. The correlogram of C_{29}ααα(20R) sterane/C_{27} sterane and Pr/Ph (Fig. 2B) also shows that the source rocks of the study area were formed in a strongly reducing saline environment and the source materials were dominated by algae.

Fig. 2 Plots of: (A) ternary plot of C_{27}ααα(20R), C_{28}ααα(20R), C_{29}ααα(20R) sterane and (B) Pr/Ph vs C_{29}ααα(20R) / C_{27}ααα(20R) sterane ratios for source rock samples from the lower Ganchaigou formation (E_3) in the Qaidam basin, China.

In addition, we detected a total of 21 dicyclic terpene and dicyclic sesquiterpenes compounds, with carbon numbers ranging between C_{12} and C_{16}. The main peak is C_{15} drimane and C_{16} homodrimane also has a high content and the dicyclic terpane distribution is similar among different samples. Previous studies have suggested that the dicyclic terpane content in geological bodies may be derived from Botryococcus (Song, et al. 1994). Our discovery of a high-abundance of Botryococcus in the algae further supports the argument that Botryococcus is an important hydrocarbon-generating material for these source rocks.

3.3 Significance of hydrocarbon generation from Botryococcus
We noted that many of the Botryococcus displayed a strong yellow fluorescence, which indicates the immense hydrocarbon-generating potential of this material. Fractionation simulation on Botryococcus from modern lakes has demonstrated (Lynch L.M. et al., 1984) that the hydrocarbon yield of this material is 0.3-76% of the dry weight of the biomass and can contribute a maximum of 85%, which is far greater than the hydrocarbon content of any other microorganism (which are almost all lower than 1%). More importantly, it can generate large amounts of hydrocarbons under low temperature (Cheng, et al. 1992; Wang et al., 1996). These discoveries coincide with the low-maturity, high-efficiency hydrocarbon-generating nature of the source rocks in E_3 of the Qaidam basin, providing further evidence that Botryococcus is an important parent material for crude oil in the study area.

4. Conclusions
Substantial numbers of Botryococcus fossils have been detected in the source rocks in the upper member of the Lower Ganchaigou Formation of the Yingxi area, Qaidam basin, China. The high Botryococcus contents and strong fluorescence indicate the high hydrocarbon-generating potential. Dicyclic terpane biomarkers, predominantly drimanes or homodrimanes with the same characteristics, also have been detected in the crude oil. Because these biomarkers are important indicators of the import of Botryococcus, Botryococcus appears to be an important oil-generating material for high-quality source rocks in the upper member of the Lower Ganchaigou Formation in the western Qaidam basin.
References
Cheng, Z.L., Li, S.J., Zhou, G.J. 1992. Character on biomarker and oil from pyrogenation of botryococcus braunil kjitzing. Nonmarine Origin Petroleum Geology, 48-52.
Duan, Y., Wang, C.Y., Zheng, C.Y. 2008. Geochemical study of crude oils from the Xifeng oilfield of the Ordos Basin, China. Journal of Asian Earth Sciences, 31:341-356.
Fu, J.M., Sheng, G.Y. 1991. Source and biomarker composition characteristics of Chinese non-marine crude oils. Acta Sedimentologica Sinica, 9:1-8.
He, Z.J., Jia, F.H., Jiang, G.X., et al. 2004. Discovery and significance of Botryococcus in Duwa area of Hetian, Xinjiang. Xinjiang Petroleum Geology, 25 (4), 400-402.
Ji, L.M., Song, Z.G., Li, J.F. 2008. Characteristic of biomarkers originating from Botryococcus in the triassic lacustrine hydrocarbon source rocks and crude oils in the Ordos basin. Acta Micropalaeontologica Sinica, 25 (3), 281-290.
Li, J.R. 1992. A discussion on the distribution and paleo-environment of tertiary botryococcus in the oil and gas area of Shan-dong province. Terrestrial Petroleum Geology, 2, 17-24.
Li, S.Y., Lin, S.J., Guo, S.H., et al. 2002. Catalytic effects of minerals on hydrocarbon generation in kerogen degradation. Journal of the University of Petroleum, China. 26(1), 69-74.
Lynch, L.M. 1984. Hydrocarbons. In: Laskin A L and H A Lechevaller ed. CRC Handbook of Microbiol. 2nd Ed. Vol. V, Microbial Products. Boca Raton: CRC Press, PP, 39-45.
Peng, P.A., Sheng, G.Y., Fu, J.M., et al. Immature crude oils in the salt lake depositional environment related to organic matter precipitated at stage of carbonate in salt lake sedimentation sequences. Chinese Science Bulletin, 45(supplement), 2689-2694.
Song, Y.T. 1991. Study on hydrocarbon of Botryococcus. Oil and Gas Geology, 12 (1), 22-33.
Wan, C.B. 1999. Discovery of algal fossils from the hailar basin and its significance. Acta Botanica Sinica, 34 (2), 140-145.
Wang, X.Z., Song, Y.T., Wang, X.J. 1996. Simulation on formation and discharge of oil. Petroleum of University Press, Beijing.
Zhou, F.Y., Peng D.H., Bian L.Z. 2002. Progress in the Organic Matter Study of Immature Oils in the Qaidam Basin. Scientia Geologica Sinica, 76 (1), 107-113.