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CHARACTERISTICS OF ORGANIC MATTER OF OIL SHALE IN THE SEQUENCE STRATIGRAPHIC FRAMEWORK AT THE NORTHERN FOOT OF BOGDA MOUNTAIN, CHINA

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Abstract. *Analysis of the abundance and type of organic matter of oil shale in the sequence stratigraphic framework of the Middle Permian Lucaogou Formation at the northern foot of Bogda Mountain, NW China, was carried out. The Lucaogou Formation consists of two well-completed 3rd order oil shale sequences, sequence 1 and sequence 2. With respect to organic matter abundance, in each sequence, the TOC of oil shale in the lowstand systems tract (LST) and the regressive systems tract (RST) is of medium abundance. The TOC of oil shale in the transgressive systems tract (TST) is of higher abundance, and in the highstand systems tract (HST), of highest. In regard to type, the organic matter of oil shale in the LST of either sequence is mainly of type II_2 or type II_1. In TST and HST, it is predominantly of type II_1 and type I, respectively, and in RST, of type II_1 or II_2. The proportion of lake algae in the organic matter of oil shale is the highest in HST, while the share of terrestrial plants is the highest in LST and RST. Being originated from lake algae and terrestrial plants, the organic matter of oil shale in TST is of mixed type.*

Keywords: *northern foot of Bogda Mountain, Lucaogou Formation, oil shale, sequence stratigraphy, organic matter characteristics.*

1. Introduction

The thick-layered oil shale is found in the Permian Lucaogou Formation at the northern foot of Bogda Mountain, Junggar Basin, NW China, which has

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a huge hydrocarbon generation potential [1, 2]. Many Chinese scientists have researched the ancient climate, sedimentary environment, oil shale deposits features and geochemistry of the Lucaogou Formation in different areas of the region [3–13]. Previous studies have shown that the Lucaogou Formation may have a potential for generating oil shale, shale oil and shale gas [4–6]. However, the characteristics of oil shale in the sequence stratigraphic framework of the formation in the study areas have not been systematically analyzed yet. This work discusses the abundance and type of organic matter of oil shale in the sequence stratigraphic framework of the Lucaogou Formation at the foot of Bogda Mountain. Although the nature of oil shale was not investigated, better knowledge of it may lay foundations for the joint exploration of the rock in the region.

2. Geological setting

The northern foot of Bogda Mountain usually refers to the areas between the eastern Tianshan Mountains and the southeastern margin of the Junggar Basin. The structural features in these areas are very complex due to the tectonic activities in different periods. A series of multiple anticlines and multistage thrust faults were well developed here under the action of intense squeezing. The Lucaogou Formation stratum was exposed on the surface because of intense tectonic activities [2] (Fig. 1).

The Lucaogou Formation stratum in the region's five areas (Yaomoshan, Tianchi, Sangonghe, Dahuangshan and Shichanggou) and one well (JZK2) were selected as an object of study (Fig. 2).

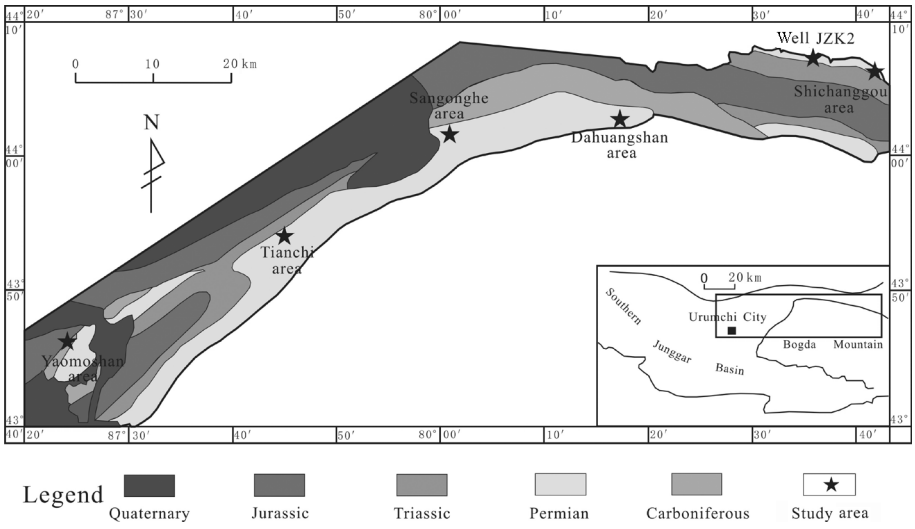

Fig. 1. Sketch map of the northern foot of Bogda Mountain and the locations of the study areas and well JZK2.

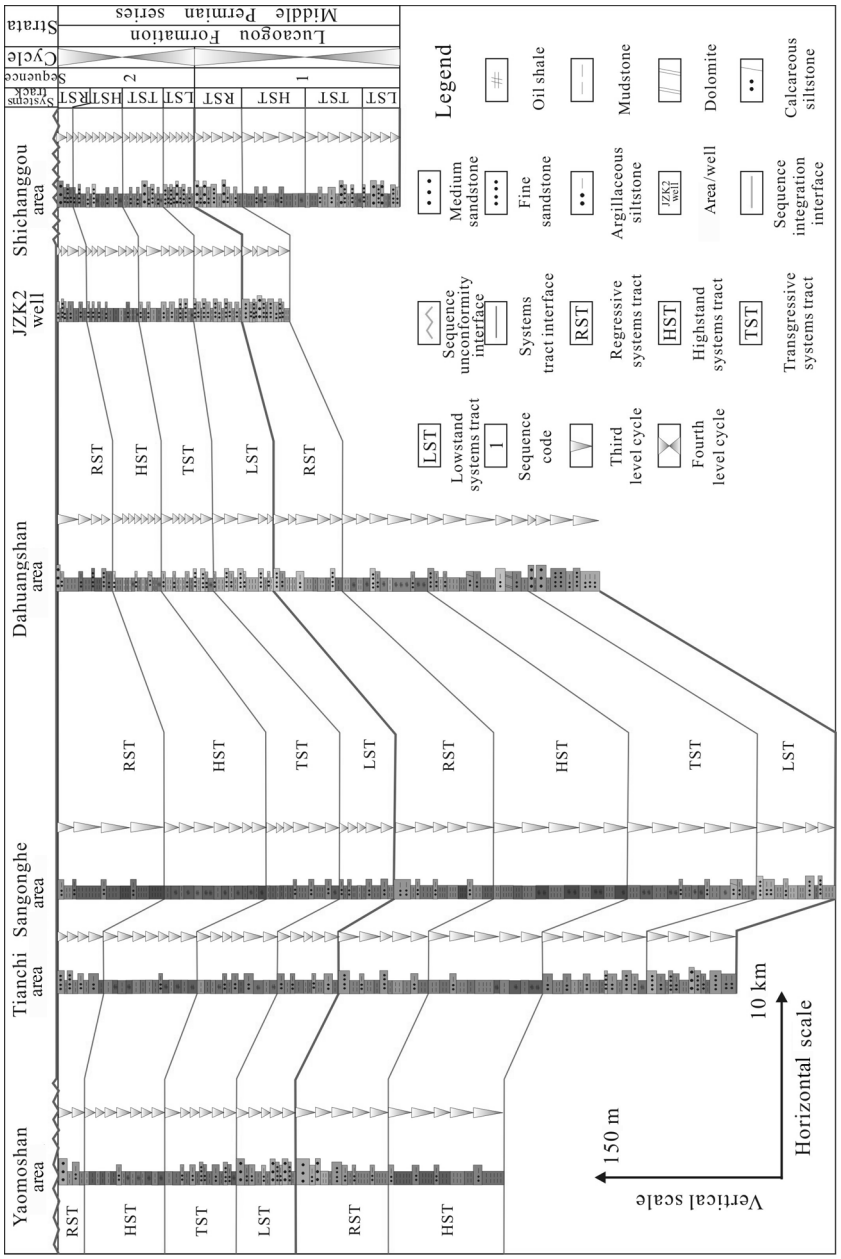

Fig. 2. The sequence stratigraphic framework features of the Permian Lucaogou Formation at the northern foot of Bogda Mountain.

3. Samples and tests

Samples for the study were taken from the Permian Lucaogou Formation stratum in the above five areas – Yaomoshan, Tianchi, Sangonghe, Dahuangshan and Shichanggou, at the northern foot of Bogda Mountain in the Junggar Basin and, in addition, nine samples were collected from well JZK2 from the same region (Fig. 2). The collected samples were mostly gray or black oil shale. Oil shale from the same areas has been investigated before and some data come from [10, 12–15]. In the current work, all the samples were analyzed for total organic carbon (TOC, wt%) and by Rock-Eval pyrolysis. TOC was determined using a LECO CS-400 instrument. The crushed sample (about 100 mg, sieved through a 120 mesh sieve) was heated from ambient temperature to 1200 °C in an induction furnace after removing carbonate material with HCl. Rock-Eval pyrolysis was carried out using a Rock-Eval 6 instrument following standard procedures [16, 17].

4. Sequence stratigraphic framework

The Yaomoshan, Tianchi, Sangonghe, Dahuangshan and Shichanggou areas and well JZK2 were selected to build the sequence stratigraphic framework of the Lucaogou Formation at the northern foot of Bogda Mountain. Based on continental sequence stratigraphy principles [18], the formation consists of two well-completed 3rd order sequences, sequence 1 and sequence 2. Each sequence consists of four systems tracts: the lowstand systems tract (LST), the transgressive systems tract (TST), the highstand systems tract (HST) and the regressive systems tract (RST), from bottom to top. The main sedimentary facies are semideep-deep lake subfacies, shallow lake subfacies and fan delta facies (Fig. 2). In addition, the sedimentary facies type and distribution characteristics in each systems tract are different.

5. Organic matter abundance features

Organic matter abundance is an important parameter to judge the quality of an oil shale.

5.1. Organic matter abundance in sequence 1

5.1.1. LST

The source rock generative potential $S_1 + S_2$ of the LST of sequence 1 in the Tianchi area (average TOC 2.79%) is good to very good. In the Sangonghe, Dahuangshan and Shichanggou areas (avg TOC 7.9%, 7.98% and 9.1%, respectively), this potential is very good (Fig. 3).

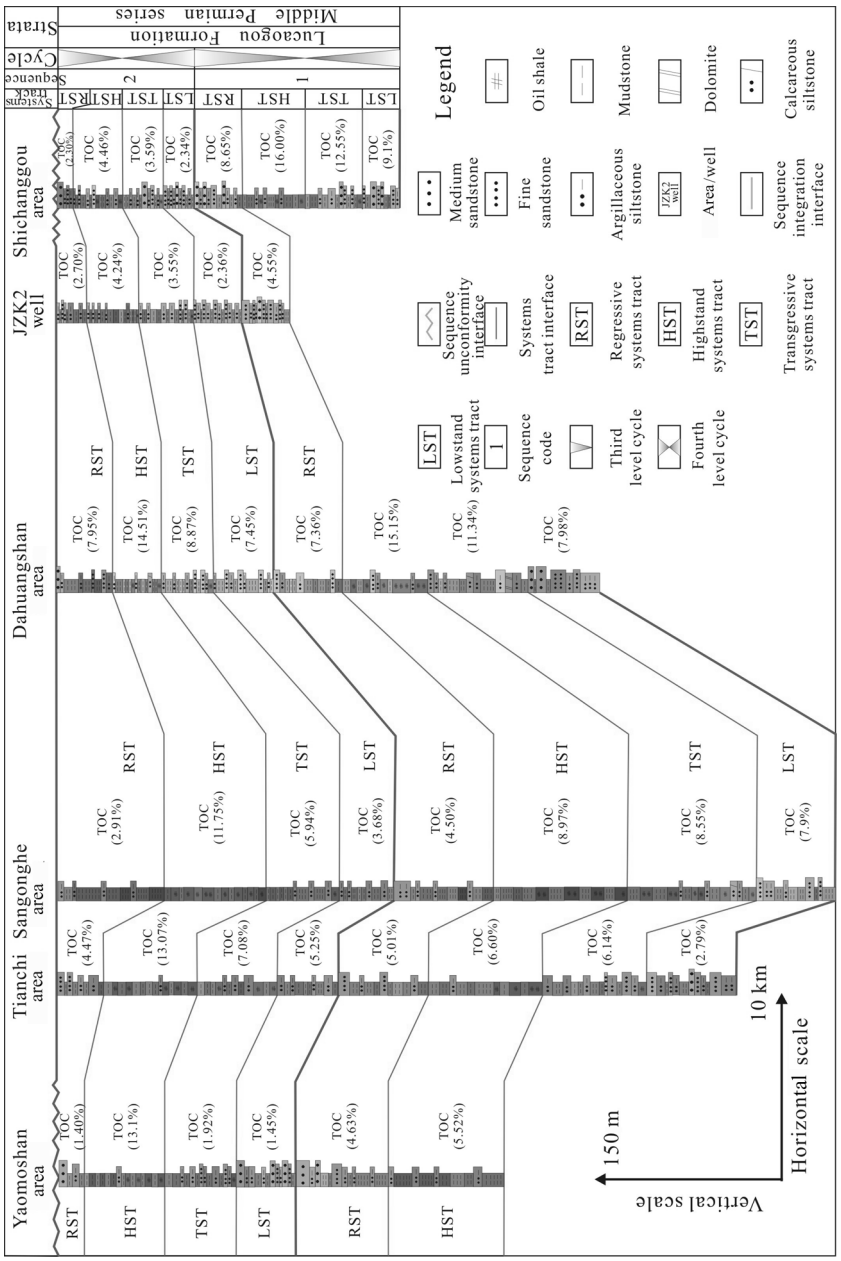

Fig. 3. The organic matter abundance features in the sequence stratigraphic framework of the Permian Lucaogou Formation at the northern foot of Bogda Mountain.

5.1.2. TST

In the TST of sequence 1, the source rock generative potential S_1+S_2 in the Tianchi (average TOC 6.14%), Sangonghe (average TOC 8.55%), Dahuangshan (average TOC 11.34%) and Shichanggou (average TOC 12.55%) areas is very good. The TOC content of oil shale in the TST of each area and well JZK2 is higher than that in LST (Fig. 3).

5.1.3. HST

The source rock generative potential $S_1 + S_2$ of the HST of sequence 1 in the Yaomoshan (average TOC 5.52%), Tianchi (average TOC 8.55%), Sangonghe (average TOC 8.55%), Dahuangshan (average TOC 11.34%) and Shichanggou (average TOC 12.55%) areas is very good. The TOC content of oil shale in the HST of the sequence in each area and well JZK2 is high (Fig. 3).

5.1.4. RST

In the RST of sequence 1, the source rock generative potential $S_1 + S_2$ in the Yaomoshan (average TOC 4.63%), Tianchi (average TOC 5.01%), Sangonghe (average TOC 8.55%), Dahuangshan (average TOC 11.34%) and Shichanggou (average TOC 12.55%) areas and well JZK2 (average TOC 8.55%) is very good. Compared with that in HST, the TOC of oil shale in RST in each area is lower (Fig. 3).

5.2. Organic matter abundance in sequence 2

5.2.1. LST

The source rock generative potential $S_1 + S_2$ of the LST of sequence 2 in the Yaomoshan area (average TOC 1.45%) is poor to good. The same potential in the Tianchi and Dahuangshan areas (avg TOC respectively 5.25% and 7.45%) is very good. In the Sangonghe area (average TOC 3.68%) and well JZK2 (average TOC 2.36%), the source rock generative potential is good to very good, and in the Shichanggou area (average TOC 2.34%), good (Fig. 3).

5.2.2. TST

In the TST of sequence 2, the source rock generative potential $S_1 + S_2$ in the Yaomoshan area (average TOC 1.92%) is fair to very good. In the Tianchi, Sangonghe and Dahuangshan areas (avg TOC 7.08%, 5.94% and 8.87%, respectively) and well JZK2 (average TOC 3.55%), this potential is very good, and in the Shichanggou area (average TOC 3.59%), good to very good. The TOC of oil shale in the TST of sequence 2 in each area is higher than that in LST (Fig. 3).

5.2.3. HST

The source rock generative potential $S_1 + S_2$ of the HST of sequence 2 in the Yaomoshan (average TOC 13.1%), Tianchi (average TOC 13.07%), Sangonghe (average TOC 11.75%) and Dahuangshan (average TOC 14.51%) areas and well JZK2 (average TOC 4.24%) is very good. Though this potential in well JZK2 is also very good, the source rock quality in the well is not as good as that in the above four areas. The source rock generative potential in the Shichanggou area (average TOC 4.46%) is good to very good. The TOC of oil shale in the HST of sequence 2 in all areas is high (Fig. 3).

5.2.4. RST

In the RST of sequence 2, the source rock generative potential $S_1 + S_2$ in the Yaomoshan area (average TOC 1.40%) is fair, but is very good in the Tianchi and Dahuangshan areas (avg TOC 4.47% and TOC 7.95%, respectively). In the Sangonghe and Shichanggou areas (average TOC respectively 2.91% and 2.30%) and well JZK2 (average TOC 2.70%), this potential is good. Compared with that in HST, the TOC of oil shale in the RST of each area is lower (Fig. 3).

6. Organic matter type features

Organic matter type is mainly determined by original biological types and their combination, which is controlled by biological living environments [19]. The kerogen in source rocks can be divided into three types: type I, type II and type III. Type I kerogen mainly comes from lake algae. Type II kerogen is divided into subtypes – type II_1 and type II_2, while type II_1 kerogen is chiefly derived from lake algae mixed with some higher terrestrial plants, and type II_2 kerogen primarily originates from higher terrestrial plants mixed with some lake algae. Type III kerogen is predominantly derived from higher terrestrial plants. Thus the type of organic matter can indicate the material's sources and sedimentary environments [20–23].

6.1. Organic matter type in sequence 1

6.1.1. LST

In the LST of sequence 1, the organic matter of oil shale in the Tianchi, Shichanggou and Dahuagnshan areas is of type II_1, which suggests that the matter is mainly derived from lake algae mixed with some higher terrestrial plants. The organic matter of oil shale in the Sangonghe area is of type I, indicating mostly the material's lake algal origin (Fig. 4).

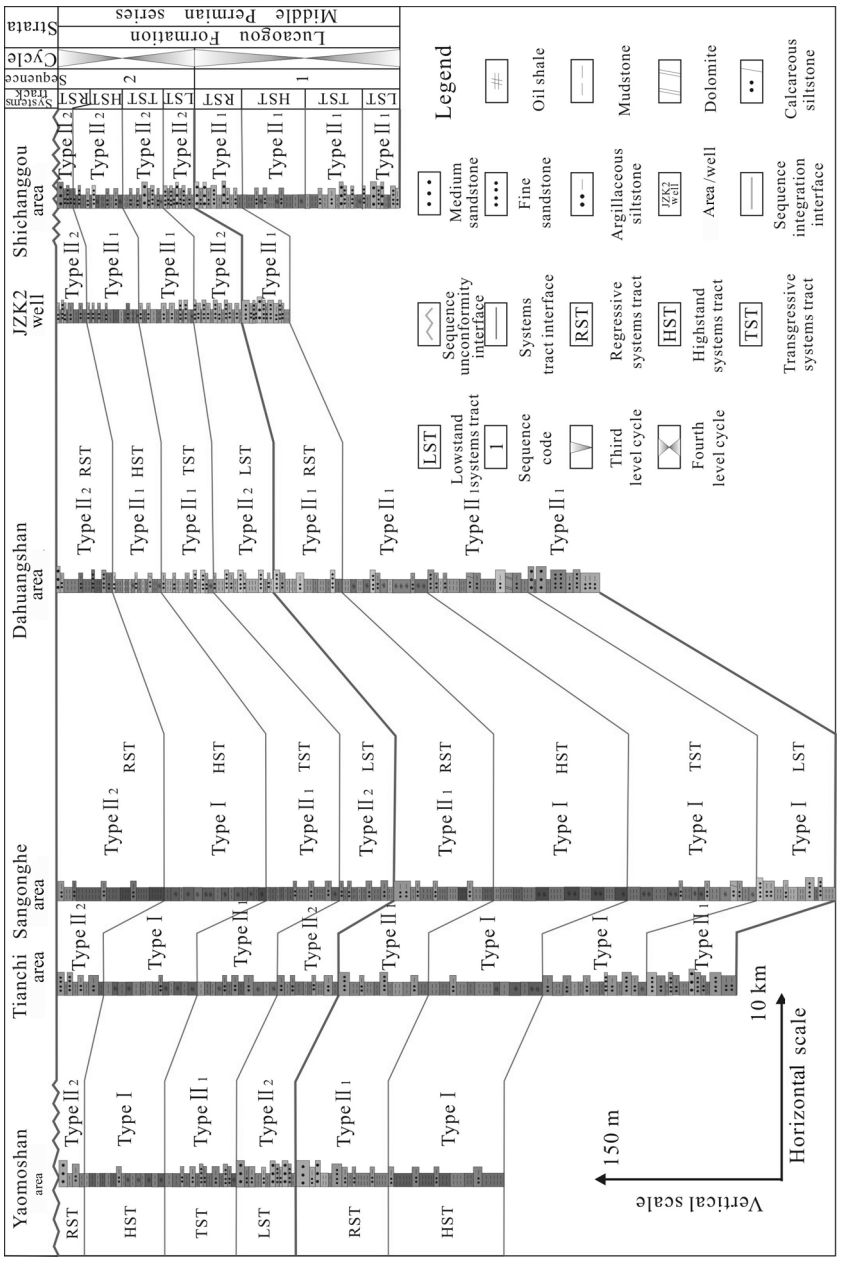

Fig. 4. The organic matter type features in the sequence stratigraphic framework of the Permian Lucaogou Formation at the northern foot of Bogda Mountain.

6.1.2. TST

The type of organic matter of oil shale in the Tianchi and Sangonghe areas is I, suggesting that the matter is mainly of lake algal origin. The organic matter of oil shale in the Dahuangshan and Shichanggou areas is of type II_1, indicating that the material is predominantly derived from lake algae mixed with some higher terrestrial plants. Unlike the organic matter type in the LST of sequence 1, it changed from II_1 to I in TST in the Tianchi area. However, the type remained unchanged in the Dahuangshan and Shichanggou areas (Fig. 4).

6.1.3. HST

The organic matter of oil shale in the HST of sequence 1 in the Yaomoshan, Tianchi and Sangonghe areas in the western parts of the Junggar Basin is of type I, which means that the matter is chiefly derived from lake algae. In the Dahuangshan and Shichanggou areas, the organic matter type is II_1, which suggests that the material primarily originates from lake algae mixed with some higher terrestrial plants (Fig. 4).

6.1.4. RST

In the RST of sequence 1, the organic matter of oil shale in all areas and well JZK2 is of type II_1, indicating that it chiefly comes from lake algae mixed with some higher terrestrial plants (Fig. 4).

6.2. Organic matter type in sequence 2

6.2.1. LST

In the LST of sequence 2, the organic matter type of oil shale in all areas and well JZK2 is II_2. This implies that the matter is mainly derived from higher terrestrial plants mixed with some lake algae. Unlike the organic matter type in the RST of sequence 1, it changed from II_1 to II_2 in the LST of sequence 2 (Fig. 4).

6.2.2. TST

The organic matter of oil shale of the TST of sequence 2 in the Yaomoshan, Tianchi and Sangonghe areas in the western parts of the Junggar Basin and in the Dahuangshan area and well JZK2 in the basin's eastern parts is of type II_1. This indicates that the organic matter is mainly derived from lake algae mixed with some higher terrestrial plants. In the Shichanggou area, the organic matter type of oil shale is II_2, implying the matter's origin from higher terrestrial plants mixed with some lake algae. Differently from the organic matter type of oil shale in the LST of sequence 2, the type changed from II_2 to II_1 in the sequence's TST in most areas and well JZK2 in the eastern parts of the Junggar Basin. However, no corresponding change took place in the Shichanggou area (Fig. 4).

6.2.3. HST

In the HST of sequence 2, the organic matter type of oil shale in the Yaomoshan, Tianchi and Sangonghe areas in the western parts of the Junggar Basin is I, indicating mainly the material's lake algal origin. The organic matter type of oil shale both in the Dahuangshan area and well JZK2 is II_1, which implies that the matter is derived from lake algae mixed with some higher terrestrial plants. In the Shichanggou area, the organic matter is of type II_2 (Fig. 4).

6.2.4. RST

The organic matter type of oil shale of the RST of sequence 2 in all areas and well JZK2 is II_2, which signifies the matter's origin mainly from higher terrestrial plants mixed with some lake algae (Fig. 4).

7. Organic matter evolution characteristics

7.1. Organic matter abundance evolution characteristics

Through the comparative analysis it can be found that the TOC evolution features in sequence 1 are similar to those in sequence 2 in the vertical direction. In each sequence, the TOC of oil shale in LST is of medium abundance and in RST, of higher abundance. In HST, the oil shale TOC is of highest abundance (Fig. 5a). The TOC evolution features in both the sequences may

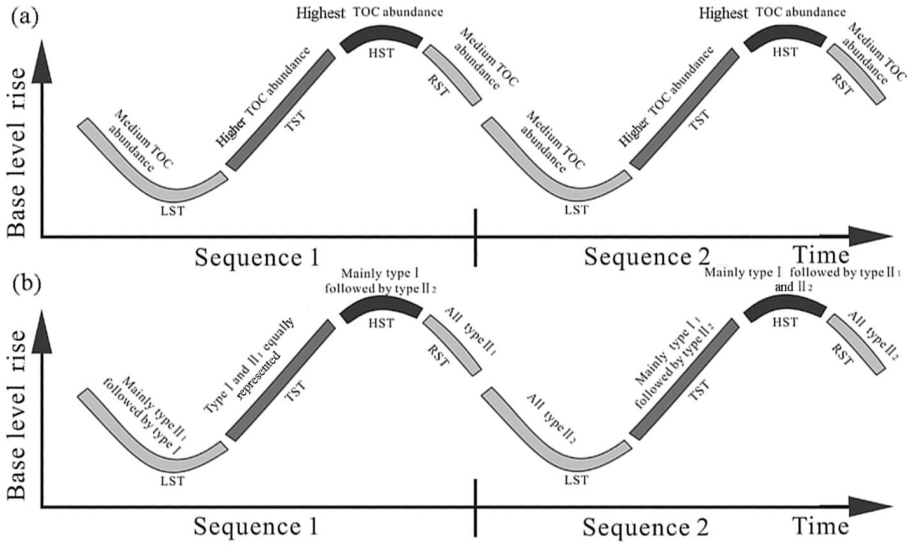

Fig. 5. The evolution characteristics of organic matter abundance and type in the sequence stratigraphic framework of the Permian Lucaogou Formation at the northern foot of Bogda Mountain: (a) evolution characteristics of organic matter abundance, (b) evolution characteristics of organic matter type.

have been controlled by changes of sediments deposition rate and accommodation space [24, 25].

7.2. Organic matter type evolution characteristics

The evolution characteristics of organic matter type in sequence 1 are a little different from those in sequence 2. The organic matter type in the LST of sequence 1 is mainly II_1, and in individual areas, I. In the TST of sequence 1, the organic matter types are II_1 and I. Compared with LST, the input volume of higher terrestrial plants in TST is smaller. The reason for this may be that the lake level gradually rose which caused the shore distance to increase. Thus the input volume of terrestrial plants in organic matter gradually decreased and the productivity of lake algae steadily increased [26, 27]. The organic matter in the HST of sequence 1 is predominantly of type I, and in individual areas, of type II_1. This may be because the productivity of lake algae further increased and the input volume of terrestrial plants in organic matter further decreased [26, 27]. The organic matter type in the RST of sequence 2 is II_1. This may be explained by that the lake level gradually dropped which caused the shore distance to reduce. Thus the input volume of terrestrial plants in organic matter gradually increased and the productivity of lake algae step-by-step decreased [26, 27] (Fig. 5b).

The organic matter type in the LST of sequence 2 is exclusively II_2. In TST, it is mainly I, and in individual areas, II_2. The reason for this may be that the lake level gradually rose which caused the shore distance to increase. Thus the input volume of terrestrial plants in organic matter gradually decreased [26, 27]. The organic matter in the HST of sequence 2 is predominantly of type I and in individual areas, of type II_1 and type II_2. The changes of organic matter type may have been due to the further rise of lake level, which may have caused the productivity of lake algae to further increase and the contribution of higher terrestrial plants to organic matter to further decrease [26, 27]. The organic matter type in the RST of sequence 2 is exclusively II_2. This may be explained by that the lake level rose, causing the productivity of lake algae to decrease and the input volume of higher terrestrial plants in organic matter to further increase [26, 27] (Fig. 5b).

8. Conclusions

The main sedimentary facies of the Lucaogou Foramtion at the northern foot of Bogda Mountain are shallow lake subfacies, deep lake subfacies and fan delta facies. The Lucaogou Formation consists of two well-completed 3rd order sequences, sequence 1 and sequence 2.

The organic matter abundance evolution features in sequence 1 are similar to those in sequence 2. In each sequence, the TOC of oil shale in LST is of medium abundance and in RST, of higher abundance. The TOC abundance of oil shale is the highest in HST.

The organic matter type of oil shale in LST is mainly II_2 or II_1. In TST, the type is predominantly II_1, in HST, mostly I. The organic matter type of oil shale in RST is II_1 or II_2. The proportion of lake algae of oil shale is the highest in HST. The share of terrestrial plants of oil shale is the highest in LST and RST. Being originated from lake algae and terrestrial plants, the oil shale organic matter in TST is of mixed type.

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REFERENCES

1. Li, C. B., Guo, W., Song, Y. Q., Du, J. F. The genetic type of the oil shale at the northern foot of Bogda Mountain, Xinjiang and prediction for favorable areas. *Journal of Jilin University (Earth Science Edition)*, 2006, **36**(6), 949–953 (in Chinese with English abstract).
2. Gao, J. P. *The Tectonic Characteristics and Petroleum Geological Conditions of Foreland Thrust Belt in the Eastern Section of the Southern Junggar Basin*. PhD thesis, Xibei University, 2008, 12–54 (in Chinese with English abstract).
3. Zhao, X. F., Zhao, Y. S., Deng, Q. Y., Song, Z. Y. Preliminary study of the sequence stratigraphy of Upper Permian Lucaogou and Hongyanchi Formations on the southern edge of Jungar Basin. *Journal of Chengdu Institute of Technology*, 1994, **21**, 112–120 (in Chinese with English abstract).
4. Wu, S. Z., Qu, X., Li, Q. Paleoclimatic conditions of Lucaogou and Huangshanjie Formations in Junggar. *Xinjiang Geology*, 2002, **20**, 183–186 (in Chinese with English abstract).
5. Li, J. J. *Study on the Oil Shale Geochemistry of Permian Lucaogou Formation in the Northern Bogda Mountain*. PhD thesis, China University of Geosciences (Beijing), 2009, 20–60 (in Chinese with English abstract).
6. Gao, Z. L., Kang, Y. S., Liu, R. H., Bai, W. H. Geological features and developmental controlling factors of Lucaogou oil shale in the southern margin of Junggar Basin. *Xinjiang Geology*, 2011, **29**, 189–193 (in Chinese with English abstract).
7. Peng, X. F., Wang, L. J., Jiang, L. P. Analysis of sedimentary environment of the Permian Lucaogou Formation in southeastern margin of the Junggar Basin. *Journal of Xinjiang University (Natural Science Edition)*, 2011, **28**, 395–400 (in Chinese with English abstract).

8. Peng, X. F., Wang, L. J., Jiang, L. P. Geochemical characteristics of the Lucaogou Formation oil shale in the southeastern margin of the Junggar Basin and its environmental implications. *Bulletin of Mineralogy, Petrology and Geochemistry*, 2012, **31**, 121–127 (in Chinese with English abstract).
9. Tao, S., Tang, D. Z., Li, J. J., Xu, H., Li, S., Chen, X. Z. Indexes in evaluating the grade of Bogda Mountain oil shale in China. *Oil Shale*, 2010, **27**(2), 179–189.
10. Tao, S., Tang, D. Z., Xu, H., Liang, J. L., Shi, X. F. Organic geochemistry and elements distribution in Dahuangshan oil shale, southern Junggar Basin: Origin of organic matter and depositional environment. *Int. J. Coal Geol.*, 2013, **115**, 41–51.
11. Zhang, M. M., Liu, Z. J., Xu, S. C., Sun, P. C. REE characteristics of the oil shale in Lucaogou Formation in Sangonghe Area, of south Junggar. *Petroleum Geology & Oilfield Development in Daqing*, 2012, **31**, 40–46 (in Chinese with English abstract).
12. Zhang, M. M., Liu, Z. J., Xu, S. C., Sun, P. C., Hu, X. F. Element response to the ancient lake information and its evolution history of argillaceous source rocks in the Lucaogou Formation in Sangonghe area of southern margin of Junggar basin. *Journal of Earth Science*, 2013, **24**(6), 987–996.
13. Zhang, M. M., Liu, Z. J., Xu, S. Z., Hu, X. F., Sun, P. C., Wang, Y. L. Analysis for the paleosalinity and lake-level changes of the oil shale measures in the Lucaogou Formation in Sangonghe area of southern margin, Junggar basin. *Petrol. Sci. Technol.*, 2014, **32**(16), 1973–1980.
14. Carroll, A. R. Upper Permian lacustrine organic facies evolution, Southern Junggar Basin, NW China. *Org. Chem.*, 1998, **28**(11), 649–667.
15. Xu, S. C. *Comparison of Oil Shale Formation Conditions between the Middle Permian Deposits of Junggar Basin and the Green River Formation of Greater Green River Basin, US*. PhD thesis, Jilin University (Changchun), 2013, 10–50 (in Chinese with English abstract).
16. Espitalié, J., Laporte, J. L., Madec, M., Marquis, F., Leplat, P., Paulet, J., Boutefeu, A. Méthode rapide de caractérisation des roches mètres, de leur potentiel pétrolier et de leur degré d'évolution. *Rev. I. Fr. Pétrol.*, 1977, **32**(1), 23–42.
17. Peters, K. E. Guidelines for evaluating petroleum source rock using programmed pyrolysis. *AAPG Bulletin*, 1986, **70**, 318–329.
18. Liu, Z. J., Dong, Q. S., Wang, S. M., Zhu, J. W., Guo, W. *Continental Sequence Stratigraphic Introduction and Application*. PhD thesis, Petroleum Industry Press, Beijing, 2002, 22–26 (in Chinese with English abstract).
19. Deng, H. W., Qian, K. *Sedimentary Geochemistry and Environmental Analysis*. PhD thesis, Gansu Science and Technology Press, Lanzhou, 1993, 1–82 (in Chinese with English abstract).
20. Zhang, H. F., Zhang, C. L., Gao, X. Z., Zhang, Z. H., Jiang, Y. L. *Petroleum Geology*. PhD thesis, Petroleum Industry Press, Beijing, 1999, 45–60 (in Chinese with English abstract).
21. Zhang, J. C., Lin, L. M., Li, Y. X., Tang, X., Zhu, L. L., Xing, Y. W., Jiang, S. L., Jing, T. Y., Yang, S. Y. Classification and evaluation of shale oil. *Earth Science Frontiers (China University of Geosciences (Beijing); Peking University)*, 2012, **19**, 322–332 (in Chinese with English abstract).
22. Ercegovac, M., Kostić, A. Organic facies and palynofacies: Nomenclature, classification and applicability for petroleum source rock evaluation. *Int. J. Coal Geol.*, 2006, **68**(1), 70–78.

23. Guo, H. J., Jia, W. L., Peng, P. A., Lei, Y. H., Luo, X. R., Cheng, M., Wang, X. Z., Zhang, L. X., Jiang, C. F. The composition and its impact on the methane sorption of lacustrine shales from the Upper Triassic Yanchang Formation, Ordos Basin, China. *Mar. Petrol. Geol.*, 2014, **57**, 509–520.
24. Passey, Q. R., Creaney, S., Kulla, J. B., Moretti, F. J., Stroud, J. D. A practical model for organic richness from porosity and resistivity logs. *AAPG Bulletin*, 1990, **74**(12), 1777–1794.
25. Peters, K. E., Snedden, J. W., Sulaeman, A., Sarg, J. F., Enrico, R. J. A new geochemical-sequence stratigraphic model for the Mahakam delta and Makassar slope, Kalimantan, Indonesia. *AAPG Bulletin*, 2000, **84**(1), 12–44.
26. Jia, J. L., Bechtel, A., Liu, Z. J., Strobl, S. A. I., Sun, P. C., Sachsenhofer, R. F. Oil shale formation in the Upper Cretaceous Nenjiang Formation of the Songliao Basin (NE China): Implications from organic and inorganic geochemical analyses. *Int. J. Coal Geol.*, 2013, **113**, 11–26.
27. Bechtel, A., Jia, J. L., Strobl, S. A. I., Sachsenhofer, R. F., Liu, Z. J., Gratzer, R., Püttmann, W. Paleoenvironmental conditions during deposition of the Upper Cretaceous oil shale sequences in the Songliao Basin (NE China): implications from geochemical analyses. *Org. Geochem.*, 2012, **46**, 76–95.

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