Differences and genesis of shale oil properties between the upper and lower sections of the Lucaogou Formation in the Jimsar Sag

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Abstract. The Lucaogou Formation is a set of saline lake sediments with high abundance of organic matter and good parent material type in the Jimsar Sag, Junggar Basin. It belongs to the best source rock. The Lucaogou Formation sandstone and shale are thinly interbedded, and the upper and lower reservoirs are oil-bearing as a whole, with source-storage integration characteristics. The upper part of the shale oil and the lower part of the shale oil in the Lucaogou Formation are more heavily oily, and the lower part of the oil is heavier. Fine geochemical analysis shows that the crude oil in the upper part of the Lucaogou Formation is formed in a sedimentary environment with certain reduction, while the lower crude oil is formed in a highly reducing and salinized environment; The parent material in the upper and lower shale oil sources in the Lucaogou Formation is mainly algae and lower aquatic organisms, but the lower aquatic organisms in the lower part are obviously dominant, and the upper and lower raw materials are significantly different. The difference of the characteristics of the shale oil in the upper and lower parts of the Lucaogou Formation is closely related to the sedimentary environment of the source rock and the source material. At the same time, the special source of the lower part of the Lucaogou Formation produces hydrocarbons in the early stage of the lower evolution stage, which makes the oil quality of the crude oil become heavier obviously.

1. Geological overview
The Jimsar Sag is located in the eastern uplift of the Junggar Basin, and is fractured and cut on three sides. It is a braided depression of the west and the east and the east and the east. From the bottom to the top, there are Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Tertiary and Quaternary strata [1, 2], of which the Permian Lucaogou Formation is thick and thin. The trend of west thick and thin east is 200-300m in thickness. It is a set of shallow-semi-deep-deep-water lake sediments. The lithology is mainly dolomite, fine sandstone, mudstone and a small amount of limestone and tuff, is a set of high quality source rocks. The sand mud of Lucaogou Formation is alternately deposited or in close contact with each other. The reservoir section is poor in physical properties. It is generally a dense reservoir with mesopores, low permeability and ultra-low permeability. The upper and lower reservoirs are oily and self-generated. The storage and source storage are integrated. At present, many wells have obtained industrial oil flow in the upper and lower sections of the Lucaogou Formation (Fig. 1).
2. Geochemical characteristics of the shale in the Lucaogou Formation

2.1. Lucaogou Formation shale organic matter abundance
The sand mud of the Lucaogou Formation is interactively distributed, and the phenomenon of crude oil infiltration is generally seen in the core. In order to ensure the accurate and reliable analysis results of source rocks, chloroform extraction of source rock samples was first carried out before the analysis of organic carbon and pyrolysis of source rocks, eliminating the analysis of external hydrocarbons.

According to the analysis of 502 samples from 16 wells, the muddy rock samples of Lucaogou Formation have the highest organic matter abundance, the TOC value is up to 15.51%, the average is 3.83%, and the hydrocarbon generation potential (S1+S2) is up to 177mg/g, an average of 18mg/g, is a good - best oil rock. Followed by dolomite, the TOC is up to 12.27%, the average is 2.64%, and the hydrocarbon generation potential (S1+S2) is 0.26mg/g~87.96mg/g, with an average of 11.70mg/g, which is a medium-good hydrocarbon source rock. The distribution of limestone source rocks is very small, with an average TOC of 2.40% and an average of 10.33 mg/g for S1+S2, which is a medium to good source rock. The abundance of silty sandstone organic matter is low, the TOC is 0.08%~1.88%, and the S1+S2 is less than 2.0mg/g, which is mainly poor source rock. The tuff TOC is less than 0.3%, mainly non-source rock. In the longitudinal direction, the upper part of the organic matter abundance is slightly higher than the lower part.

2.2. Organic matter types of source rocks in Lucaogou Formation
The parent material type of the source material of the Lucaogou Formation is generally preferred, but there is a very strong heterogeneity, and the organic matter type has a wide range. The results of pyrolysis hydrogen index and kerogen analysis showed that the upper part of the Lucaogou Formation had a hydrogen index of 52mg/g~808mg/g, an average of 347mg/g, and a kerogen H/C ratio of 0.76 to 1.37, with an average of 1.24. The main types are type I, type II1 and type II2; the hydrogen index of
dolomite is 73mg/g-526mg/g, the average is 201mg/g, the ratio of kerogen H/C is 1.35-1.37, and the total parent type is II₁, II₂. In the lower part of the Lucaogou Formation, the hydrogen index of mudstone is 89mg/g -587mg/g, with an average of 351mg/g, and the kerogen H/C ratio is 1.13 to 1.51, which is mainly characterized by type III and II₂. The hydrogen index of dolomite and siltstone are all lower than 200mg/g, which are mainly type III parent materials. There are subtle differences in the parent material types of the upper and lower hydrocarbon source rocks.

2.3. Organic matter maturity of source rocks in Lucaogou Formation
The source rocks of the Permian Lucaogou Formation in the Jimsar Sag are generally in the low- -medium maturity stage. The vitrinite reflectance (Ro) of the source rocks in the eastern slope is 0.52%-0.78%, and the Tmax value of the pyrolysis is 433 °C-445 °C, low maturity - near maturity, in the middle of the depression with the increase of buried depth, Ro is 0.92%-1.04%, the thermal decomposition Tmax value is mostly concentrated between 446 °C-452 °C, the source rock is at in the middle mature stage of evolution, it began to enter a large number of hydrocarbon generation and discharge stages.

The overall the parent material type of the Lucaogou Formation source rock is good, and it is in the mature stage of evolution, and the best source rock, with strong hydrocarbon generation capacity, is a set of high quality source rocks. In the longitudinal direction, the hydrocarbon generation capacity of the lower source rock is stronger than that of the upper section.

3. Characteristics of shale oil in Lucaogou Formation

3.1. Physical characteristics
The oil quality of the shale oil in the Lucaogou Formation is generally biased, which is different from the Chang 7 tight oil in the Ordos Basin. The density of crude oil in the upper part of Lucaogou Formation is 0.8714g/cm³~0.8991g/cm³, and the average viscosity is 49.2mPa.s. The oil quality of the lower crude oil is relatively heavier, the density is 0.8945g/cm³~0.9193g/cm³, and the viscosity average is 143.9mPa.s, the lower section is heavier than the upper section(Table 1).

| Group      | Well number | Depth (m) | Density (g/cm³) | Viscosity (mPa.s) |
|------------|-------------|-----------|-----------------|-------------------|
| Upper section | J23        | 2309-2385 | 0.8714          | 156.6             |
| Upper section | J31        | 2707-2746 | 0.889           | 30.1              |
| Upper section | J25        | 3403-3425 | 0.8964          | 55.2              |
| Lower section | J31        | 2875-2945 | 0.908           | 132.9             |
| Lower section | J31        | 2916-2931 | 0.9136          | 189.0             |
| Lower section | J174       | 3255-3314 | 0.9193          | 290.3             |
3.2. **Light hydrocarbon composition**

Among the light hydrocarbon (C_7) composition of crude oil, n-heptane, methylcyclohexane and dimethylcyclopentane have clear source-directed meanings, which can reveal the origin and source of crude oil. The light hydrocarbon composition of the shale oil in the Lucaogou Formation is characterized by low methylcyclohexane content and high dimethylcyclopentane content, which is significantly different from other crude oil compositions in the Junggar Basin. The content of crude heptane, methylcyclohexane and dimethylcyclopentane in the upper part of the Lucaogou Formation is 24%~32%, 27%~34%, 41%~45%, respectively. The lower crude oil is n-heptane, and the cyclohexane content is lower than that of the upper part, and the content of dimethylcyclopentane is very high, ranging from 47% to 65%, reflecting that the crude oil parent material of the upper part of the Lucaogou Formation is mainly low-grade aquatic organisms, and the contribution of algae and higher plants. Relatively more, the crude oil parent material of the lower section is mainly low-lying planktonic aquatic organisms, and there is a significant difference in the source composition of crude oil parent material.

3.3. **Characteristics of saturated hydrocarbons**

In the chromatographic composition of saturated hydrocarbons, the normal paraffins of the upper and lower crude oils of the Lucaogou Formation are well distributed, and the main peak carbon is nC_23. Among the isoparaffin compositions, the crude oil in the upper section was relatively large, Pr/Ph was 1.2-1.6, the average values of Pr/nC17 and Ph/nC18 were 1.10 and 0.84, respectively, while the Pr/Ph of the lower crude oil was significantly smaller, ranging from 0.99 to 1.12, and Pr/nC17 and Ph/nC18 were significantly larger, with mean values of 1.52 and 2.11, respectively. The upper crude oil has lower β-carotane and higher Ts. The lower crude oil has high abundance of β-carotane, and the Ts is very low, reflecting that the upper parent crude oil forming environment has certain reduction, and the lower crude oil parent material formation environment is salt, strong reducing. The comparison of regular decane composition shows that the average values of C_27, C_28 and C_29 in the upper section are 20%, 35% and 40%, respectively. The lower crude oil C_27 decane content is smaller, the average value is 14%, and the C_29 decane content is relatively large, the average is 52%. The carbon isotope value of the upper crude oil is about -32.25‰, which is 1.1‰ lighter than the lower crude oil. It is concluded that the source of crude oil in the upper and lower sections of the Lucaogou Formation is significantly different. The upper part of the crude oil has higher algae content, and the lower part of the crude oil is mainly lower aquatic organisms.

4. **Origin of shale oil in Lucaogou Formation**

The shale oil in the Lucaogou Formation is inter-deposited or closely contacted. The characteristics of the upper shale oil are very similar to those of the upper source rock in close contact. The properties of the lower shale oil and the lower source rock are very consistent. The shale oil is mainly from the source rock formation in close contact with it, which is short-distance migration and near-source accumulation. The oil quality of the shale oil in the Lucaogou Formation is relatively heavy, and the deep oil quality is heavier. The oil quality is not affected by biodegradation. The chromatographic analysis of crude oil by total hydrocarbons showed that the composition of the upper and the lower crude oil was intact and the crude oil was not biodegraded. The oil quality of the Lucaogou Formation is mainly related to the specific sedimentary environment, the special source matrix composition and the maturity of the source rock. Firstly, the source rocks of the Lucaogou Formation are now in the low mature-mature evolution stage, and the maturity of the generated crude oil is low. Secondly, the source material of the Lucaogou Formation is good, algae and low-level planktonic aquatic organisms are very developed, and the crude oil isomers and naphthenes are relatively high, and the crude oil quality is heavy. The source rocks in the lower part of the Lucaogou Formation are in a strong reducing environment of salinization, and low planktonic aquatic organisms are very developed. These mothers can produce
hydrocarbons in the low-mature evolution stage to form heavy oil. These factors together determine the unique properties of the shale oil of the Lucaogou Formation.

5. Conclusion
1) The Permian Lucaogou Formation shale in the Jimsar Sag is a set of high-quality source rocks, the mudstones reach the standard of good-best source rocks, and the dolomites are medium-preferred oil-bearing rocks with good organic matter types. Algae and lower aquatic organisms are extremely developed and are in the stage of low maturity-mature evolution. They are the main source rocks of shale oil in this area, and have strong hydrocarbon generation potential, and are the most promising source rock formations.
2) The shale oil of the Lucaogou Formation comes from source rocks in close contact with the reservoir and migrates to the near source in short distances. The difference between the upper and lower shale deposits is determined by the different shale sedimentary environments and the source composition.
3) The shale oil quality in the Lucaogou Formation is related to the low mature thermal evolution of the source rocks, and is closely related to the early hydrocarbon generation of low-lying phytoplankton in the Lucaogou Formation.

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