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Jurassic Source Rock Characteristics and Resource Evaluation in Junggar Basin

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ABSTRACT

Junggar Basin is one of the important petroliferous basins in China. Based on sedimentology, palaeogeography, geochemical characteristics, tectonic thermal evolution and other aspects, this study analyzes the characteristics and distribution law of source rocks, and predicts the total oil and gas resources of Jurassic in the basin. Middle and Lower Jurassic is the main hydrocarbon source rock strata of Jurassic, and a large set of thick coal and dark mudstone are developed on delta, shore-shallow lake and deep lake facies in the basin, among which Badaowan Formation is 200 ~ 800 m thick; Xishanyao Formation is 50m ~ 550m thick, which has great development prospect, but there are few exploration results at present. Through geochemical index analysis and thermal evolution simulation of source rocks, the middle and lower Jurassic source rocks are mostly medium-good source rocks, and the distribution and thermal evolution degree of mature source rocks in the south and east of the basin are higher than those in the north and west of the basin, so they have the conditions for mass production of hydrocarbons.

KEYWORDS

Junggar Basin; Jurassic coal measures source rocks; Sedimentary environment; Control factors.

1. INTRODUCTION

The Junggar Basin is one of China's significant petroleum exploration basins, encompassing an area of approximately 130,000 km². Influenced by multiple phases of compressional tectonic movements, its basement features a north-to-south gradient with a scoop-like characteristic[1, 2], and the sedimentation, confined by the basement's features, thickens progressively from north to south and from west to east, accompanied by the development of several sedimentary depressions. Jurassic strata are ubiquitous across the basin, predominantly representing a fluvial-deltaic-lacustrine depositional system[3], reaching their maximum thickness, nearly 4000 m, along the basin's southern margin at the mountain-front thrust belt[4]. The Junggar Basin's southern edge shares a comparable sedimentary history and tectonic evolution with the Kuqa Depression[5, 6]; however, the discovered Jurassic commercial hydrocarbon reservoirs inadequately correlate with the prolific characteristics of Jurassic source rocks in the basin[7-10]. Consequently, a more meticulous assessment is required for the hydrocarbon resource potential and controlling factors of the Jurassic system in this basin.The primary Jurassic source rocks are the Bayanwula Formation (J1b), Sangonghe Formation (J1s), and Xishanyao Formation (J2x) from the Middle to Lower Jurassic, with the Bayanwula Formation (J1b) and Xishanyao Formation (J2x) hosting exceptionally thick coal-bearing source rocks. Coal and carbonaceous mudstones, as high organic carbon source rocks, exhibit considerable hydrocarbon generation potential. Therefore, this study aims to reevaluate the hydrocarbon generation capacity of Jurassic coal-bearing source rocks in the Junggar Basin by analyzing the relationship between their development and the distribution of hydrocarbon resources. This analysis encompasses an examination of the basin-wide sedimentary environment, regional geochemical characteristics, structural configurations, and reservoir-seal combinations to further appraise the resource potential of these coal-bearing source rocks in the Junggar Basin [11].

2. GEOLOGICAL SETTING

The Junggar Basin is located in the northern part of Xinjiang, surrounded by Tianshan Mountains, Altai Mountains, Zaire Mountains and other mountains, presenting a triangular basin extending in the NE direction. The Junggar Basin is formed by the convergence and collage of the Tarim block, the Siberian plate, the Kazakhstan plate and micro-plots[2, 11] . Since the Late Paleozoic, the basin has successively experienced the Indosinian-Hercynian movement stage, the Yanshan movement stage and the Himalayan orogeny stage[2], the continuously developed foreland basin provides a huge accommodating space for a large number of sediments.

Badaowan Formation, Sangonghe Formation, Xishanyao Formation, Toutunhe Formation, and Karaza Formation are developed in Jurassic strata, and the top and bottom of the strata are in unconformity contact with Cretaceous strata and Triassic strata in the whole area. The Jurassic Yanshan movement rose, the western part of the basin was uplifted, the Jurassic strata were raised, the strata of the Sangonghe Formation and the Xishanyao Formation in the central and western Shawan Depression and the southern part of the western depression of Basin Well were eroded, and the residual thickness was 0~100m[12]. The strata of the Qigu Formation and the Karaza Formation of the Upper Jurassic were strongly eroded and only preserved in the piedmont around the basin[13].

3. SOURCE ROCK DISTRIBUTION

The Jurassic source rocks are mainly coal, carbonaceous mudstone and dark mudstone of Badaowan Formation (J1b), Sangonghe Formation (J1s), Xishanyao Formation (J2x), with high organic carbon content[14], so they are the main evaluation target strata. The coal and mudstone follow the distribution law of thickening from the north to the south margin of the basin through the analysis of the connecting well profile, and the sedimentary thickness is between 100-1000m.Three coal-accumulating belts were formed in the Dushanzi-Fukang area in the south margin of the basin, Mahu Depression in the northwest margin of the basin, and the eastern area of the basin. The thickness of the coal seams is more than 20m. The coal thickness of the Badaowan Formation and Xishanyao Formation in the eastern segment of the Fukang Depression in the south margin is 30-60m. In addition, the Xishanyao Formation formed a secondary coal accumulation center in the Wulungu Depression under the division of the continental beam uplift. The number of coal seams is 15-18, the thickness of a single layer is mostly less than 2m, the development depth is concentrated in 500-900m, and the local stratum denudation burial depth is relatively shallow at 200-600m.

During the period of Badaowan Formation, the sedimentary center was located in the West-Fukang Depression of Basin Well, and the maximum accumulated thickness of dark mudstone was more than 550m, followed by Sikeshu Depression, with the accumulated thickness of mudstone reaching more than 300m. Affected by the shrinkage of the lake basin, the sedimentary center of the Xishanyao Formation is limited to the Fukang Depression, and the secondary sedimentary center is separated in the Wulungu Depression[15]. The cumulative sedimentary thickness of the mudstone in the Fukang Depression is greater than 450m, and the cumulative thickness of the mudstone in the Wulungu Depression is greater than 250m. The central and western parts of the Shawan Depression were tectonic uplifted at the end of the sedimentary period of the Xishanyao Formation, and the strata of the Xishanyao Formation in the Depression were eroded on a large scale. Only 50-100m thick dark mudstone was preserved in the eastern part of the Depression.

According to statistics, the total organic carbon (TOC) content of dark mudstone in Badaowan Formation is between 0.15% and 10.6%, with an average of 1.70%, the hydrocarbon generation potential S1 + S2 is 0.13~6.89 mg/g, with an average of 2.97 mg/g, and the chloroform asphalt "A" content is different greatly, ranging from 0.01% to 0.8%, with an average of 0.06%; The organic carbon content (TOC) of the carbonaceous mudstone in Badaowan Formation ranges from 5.9 to 43.19%, and the average organic carbon content (TOC) is 21.17%; The hydrocarbon generation potential of S1 + S2 ranged from 0.55 to 145.78 mg/g, with an average of 48.51 mg/g; The content of "A" in chloroform asphalt is between 0.0275% and 0.7%; The organic carbon content (TOC) of Badaowan Formation coals ranges from 41.6% to 82.56%, and the average organic carbon content (TOC) is 61.7%.

The hydrocarbon generation potential of S1 + S2 is 63.6~329mg/g, with an average of 158.87mg/g; The content of "A" in chloroform asphalt is 0.05%~4.12%. Therefore, the dark mudstone of Badaowan Formation is a poor-medium source rock, while the carbonaceous mudstone and coal are medium-good source rocks.

The content of organic carbon (TOC) in the shale of Xishanyao Formation is 0.26~12.63%, with an average of 1.42%; The hydrocarbon generation potential of S1 + S2 is 0.13~16mg/g, with an average of 2.03 mg/g; The content of "A" in chloroform asphalt is 0.01%~0.2%, with an average of 0.074%; The average organic carbon content (TOC) of carbonaceous mudstone in Xishanyao Formation is 18.23%; The average hydrocarbon generation potential of S1 + S2 is 20.11 mg/g; The average organic carbon content (TOC) is 63.86%; The hydrocarbon generation potential of S1 + S2 ranged from 63.6 to 181.46 mg/g, with an average of 90.24 mg/g; The content of "A" in chloroform asphalt ranges from 0.01% to 4.12%, with an average of 1.85%, so the dark mudstone and coal rocks are mostly medium source rocks, and the carbonaceous mudstone is medium-good source rocks[16].

Therefore, the overall hydrocarbon-generating capacity of the Badaowan Formation is better than that of the Xishanyao Formation, and the dark mudstone is a poor-medium source rock as a whole, with limited hydrocarbon-generating capacity; The carbonaceous mudstone and coal rock as a whole are medium-good hydrocarbon source rocks with mainly gas generation and accompanying oil generation.

4. HYDROCARBON SOURCE ROCK THERMAL EVOLUTION

Through simulating the hydrocarbon generation histories of typical depressions across different regions of the basin, it is revealed that the Lower Jurassic source rocks in the Mahu and Ulungur depressions in the basin's northern part entered the low maturity stage during the Early-Middle Cretaceous, initiating oil generation. Conversely, the Middle Jurassic source rocks, following uplift during the Late Cretaceous and Early Paleogene, remain in the immature stage to this day. In Well Puyi-1's western depression, the Jurassic source rocks lack Middle to Upper Jurassic sections, with the preserved Lower Jurassic Baoyuanwan Formation exhibiting vitrinite reflectance values ranging from 0.7% to 1.0%. These source rocks crossed the hydrocarbon generation threshold during the Lower Cretaceous under persistent tectonic subsidence, placing them currently in the mature stage, actively generating oil[17].

In the eastern region, Well Fuyi-11 witnessed its Jurassic source rocks reaching the hydrocarbon generation threshold by the end of the Jurassic period, peaking in hydrocarbon generation during the Cretaceous, and largely transitioning into the mature to highly mature stages by the end of the Cretaceous. The Siskuitu depression experienced its Lower Jurassic source rocks entering the low maturity stage during the mid to late Paleogene, followed by rapid burial during the Neogene, which propelled both the Middle and Lower Jurassic source rocks into the highly mature stage, with vitrinite reflectance (Ro) commonly ranging between 1.0% and 1.3%.

In the central segment of the basin's southern margin, the hydrocarbon source rocks at Well Hu-2, buried beyond 8000 meters, have undergone increased maturity levels (Ro values ranging from 1.1% to 2.5%) due to continuous deep burial and warming, positioning them in the highly to over-mature stages, primarily gas-prone. This finding is corroborated by the gas fields at Manas-Hutubi [18,19].

5. PALAEOGEOGRAPHICAL ENVIRONMENT

In the Mahu Depression on the northern margin of the Junggar Basin, during the early deposition of the Baoyuanwan Formation, the main sediment supply originated from adjacent mountains, resulting in the development of alluvial fans dominated by conglomerates and sandy conglomerates. Subsequent infill and later transgression led to the widespread establishment of stable aquatic environments such as littoral-shallow lakes, floodplains, and delta plains conducive to reducing conditions[14], while the basin's steady subsidence provided accommodation space for the accumulation of thick source rocks. In the Wulungu Depression, the Baoyuanwan Formation period experienced local basement uplift and subsidence[18], creating an unstable coal-forming environment unfavorable for the formation of thick coal seams. During the Xishanyao Formation period, as the lake basin shrank, the Wulungu Depression was segmented by land ridges, forming a semi-deep lacustrine setting; fluctuations in lake level, initially decreasing then rising, led to the formation of extensive delta plains and floodplains, which became key environments for coal accumulation. Meanwhile, in the Mahu Depression, ongoing regression and slowing basement subsidence resulted in increased content of sandstone and gravel, leading to thinner development of coal-bearing source rocks.

The southern margin of the Junggar Basin is the most prolific region for Jurassic source rocks, with the sedimentary center migrating eastward in the Middle East section throughout the Jurassic period[21]. In the West segment, the Siskuitu Depression primarily developed delta plains, delta front, littoral-shallow lakes, and semi-deep to deep lacustrine facies. During the deposition of the Baoyuanwan Formation, the depression's northern gentle slope received sediment supplies from both the Zayir Mountain and Chepaizi Uplift[20]. Subsequent lake transgressions caused the delta plains to become marshy, facilitating the formation of complete coal-bearing sequences, while small-scale coal-bearing rocks developed at the forefront of fan deltas on the steep southern slope. In the Xishanyao Formation stage, influenced by lake shrinkage and earlier infill, water depths decreased, leading to the development of extensive floodplains and delta plains under weakly reducing to weakly oxidizing conditions[13], which were not favorable for coal formation. However, in the remaining shallow lacustrine areas, a thick suite of dark mudstones was deposited.

6. CONCLUSION

(1) The organic matter types of coal measures source rocks in Junggar Basin are poor, and the main organic matter types are II2 and III, and the organic matter types of a few carbonaceous mudstones in the northern margin of the basin can reach II1. The organic matter abundance of source rocks in the basin is relatively high, and the dark mudstone is basically a poor-medium source rock, with limited hydrocarbon generation capacity; The carbonaceous mudstone and coal rock as a whole are medium-good hydrocarbon source rocks with mainly gas generation and accompanying oil generation.

(2) The distribution characteristics of source rocks of coal measures in the Middle and Lower Jurassic are controlled by the evolution of sedimentary facies. Coal rocks and carbonaceous mudstones are mostly developed in delta plains and delta fronts, and dark mudstones are mostly developed in semi-deep lake-deep lake facies. The tectonic framework of the basin controls the maturity of Jurassic coal measures source rocks, and the maturity increases from north to south, and the thermal evolution degree reaches the mature-overmature stage in some areas of the southern margin. Multi-stage

tectonic activities formed complex deep faults that penetrated up and down, connected different source beds and reservoirs, formed effective migration channels, and improved the efficiency of oil and gas migration and accumulation. Jurassic continuous and intermittent reservoir-cap assemblages provided high-quality conditions for oil and gas accumulation.

(3) The mature source rocks of Middle and Lower Jurassic in Junggar Basin are mainly distributed in the thrust belt of the southern margin of the basin, Sikeshu Depression, west margin of Basin Well-east margin of Shawan Depression, Fukang Depression, Wucaiwan-Dongdaohaizi Depression in the eastern part of the basin and Wulungu Depression in the northern part of the basin. The source rocks are thick and stable, and all of them have entered the oil generation window stage, and some of the source rocks in areas with large burial depth have entered the condensate-gas generation stage and dry gas generation stage.

CONFLICTS OF INTEREST

I declare that the authors have no conflict of interest.

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REFERENCES

[1] CHEN F J, WANG X W, WANG X W. “Prototype and tectonic evolution of the Junggar basin, northwestern China”, Earth Science Frontiers, Vol.03, pp. 77-89, 2005.

[2] HE D F, ZHANG L, WU S T, et al. “Tectonic evolution stages and features of the Junggar Basin”, Oil＆Gas Geology, Vol. 39(05), pp. 845-861, 2018.

[3] ZHU X, LI S, WU D, et al. “Sedimentary characteristics of shallow-water braided delta of the Jurassic, Junggar basin, Western China”, Journal of Petroleum Science and Engineering, Vol.149, pp. 591-602,2017.

[4] DING Y C, XIANG Y J, ZHAO J Y, et al. “Types of Composite Anticlines and Pool Formation Characteristics of the Lower Play in Southerm Margin of the Junggar Basin”, Xinjiang Geology, Vol.39(02), pp. 254-263, 2021.

[5] FAN S, LU Y H, LI L, et al. “Geochemical characterstics, distribution and petroleum geological significance of Triassic-Jurassic source rocks in the Tugeerming and surrounding areas of Kuga Depression, Tarim Basin”, Natrual Gas Geoscience, Vol. 33(12), pp. 2074-2086, 2022 .

[6] WEI D T, ZHAO Y C, A B L M T, et al. “Difference of Hydrocarbon Accumulation in the Foreland Thrust-fold Belt of the Southern Junggar Basin”, Geological Journal of China Universities, Vol.16(03), pp. 339-350, 2010.

[7] LI J, HAO A S, QI X N, et al. “Geochemical characteristics and exploration potential of Jurassic coal-formed gas in northwest China”, Natural Gas Geoscience, Vol.30(06), pp. 866-879+924, 2019.

[8] CHEN J P, LIANG D G, WANG X L, et al. “Oi-source identification for the mixed oils derived from multiple source rocks in the Cainan Oilfield, Junggar Basin, Northwest China”, Part l: Fundamental geochemical features of source rocks. Petroleum Exploration and Development, Vol.04), pp. 20-24, 2003.

[9] CHEN J P, WANG X L, DENG C P, et al. “Geochemical Features of Source Rocks and Crude Oil in the Junggar Basin, Northwest China”, Acta Geologica Sinica, Vol. 90(01), pp.37-67, 2016.

[10] NATALIN B, BURTMAN V. “Evolution of the Altaid Tectonic Collage and Paleozoic Crustal Growth in Eurasia”, Nature, Vol. 364, 1993.

[11] WU K Y, CHA M, WANG X L, et al. “Further Researches on the Tectonic Evolution and Dynamic Setting of the Junggar Basi”, Acta Geologica Sinica, Vol. 03, pp. 217-222, 2005.

[12] FANG S H, JIA C Z, GUO Z J, et al. “New view on the Permian evolution of the Junggar basin and its implications for tectonic evolution”, Earth Science Frontiers, Vol. 03, pp. 108-12, 2006.

[13] JIA J D. “The geology features and distribution of natural gas in junggar basin. Natural Gas Geoscience”, Vol.04, pp. 449-455, 2005.

[14] ZHANG L, NIU J Q, ZHANG P X. “The Deposition Environment and Coal Accumulation Discipline of Kamustte Mining Site in Xinjiang”, Xinjiang Geology, Vol. 30(04), pp. 482-48, 2012.

[15] QIAN Y, WANG Z D, ZHANG T, et al. “Geochemical characteristic of Jurassic source rocks and natural gas in the easter Jungar Basin and exploration potential of low-mature”, Acta Petrolei Sinica, Vol.38(01), pp. 44-54, 2017.

[16] LI Y J, WANG T D, ZHANG Y Y, et al. “Natural Gas Genesis and Formation of Gas Pools in the South Margin of Junggar Basin”, Acta Sedimentologica Sinica, Vol. 03, pp. 529-534, 2004.

[17] ZHU W, WANG R, LU X C, et al. “Yanshanian Tectonic Activities and Their Sedimentary Responses in Northwestern Junggar Basin”, Earth Science, Vol.46(05), pp. 1692-1709, 2021.

[18] YANG H B, CHEN L, KONG Y H. “New scheme of tectonic unit division in Junggar Basin”, Xinjiang Petroleum Geology, Vol.06, pp. 686-688., 2004.

[19] SHAO L Y, XU X T, WANG S, et al. “Research progress of palaeogeography and palaeoenvironmental evolution of coal-bearing series in China”, Journal of Palaeogeography, (Chinese Edition) Vol. 23(01), pp. 19-38, 2021.