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RESEARCH PAPER

Control factors of high and stable production of Jurassic Da'anzhai Member tight oil in central Sichuan Basin, SW China

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Abstract: By systematically analyzing the basic geological characteristics of tight oil in Jurassic Da'anzhai Member in the middle of Sichuan Basin (Central Sichuan area) and combining with a large number of exploration and development data, we examine the main controlling factors and exploration direction for high and stable production of tight oil. Tight oil in the Da'anzhai Member has the following characteristics: large and low abundance resources; generally tight, relatively high quality reservoirs; adjacent source rocks and reservoirs, favorable migration and accumulation of oil; extensive oil-bearing pores. Development practice reveals that the high and stable production oil wells for tight oil are mainly distributed in fractured vuggy reservoirs in the shore-lacustrine sedimentary subfacies, and fractures are very important in affecting the high and stable production of tight oil in the Da'anzhai Member. Natural gas plays an important role (gas drive) in petroleum migration and accumulation and high production of oil wells. Combined with the characteristics of high and stable production, exploration and development results, drilling cost and other factors, it is considered that the Da'anzhai Member located in the middle and south part of Sichuan Basin is a promising field for exploration and development of tight oil in the Jurassic of the Sichuan Basin.

Key words: Sichuan Basin; Jurassic system; Da'anzhai Member; tight oil; shell limestone; high and stable production; controlling factors

1. Introduction

The oil of the Sichuan Basin is mainly distributed in the Jurassic in the middle of the basin (Fig. 1), in which the Da'anzhai Member has a cumulative proven reserves of more than 7 500×10^4 t, accounting for 92.8% of the total proved reserves of the Jurassic; and has produced over 400×10^4 t of crude oil cumulatively, accounting for 82.3% of the Jurassic cumulative oil production, which shows the importance of the Jurassic tight oil in the oil production of the Sichuan Basin[1–3]. Although some exploration and development results have been achieved, but the annual output of the basin has maintained at about 10×10^4 t, failing to reach the development of scale benefit. During the "Twelfth Five-year Plan" period, propelled by the advancement of tight oil theory, the Jurassic System of the Sichuan Basin has been investigated intensively, but some problems remain unanswered: Shell limestone reservoirs of Da'anzhai Member are high in densification degree,

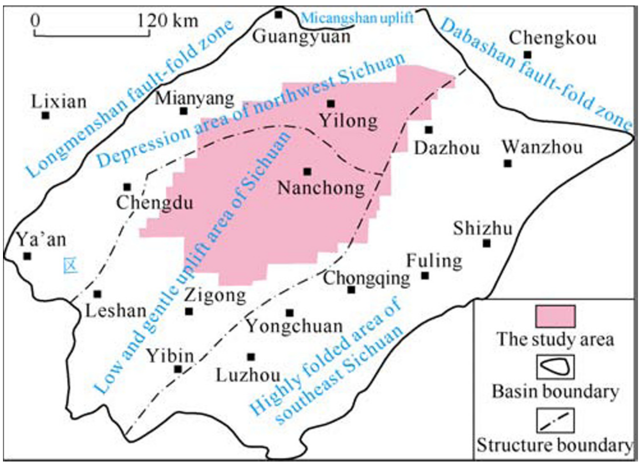

Fig. 1. Location of the study area.

strong in heterogeneity, and complicated in enrichment law, but against all these, it has produced over 400 × 10^4 t of oil, and over 100 wells have cumulative output of over 1 × 10^4 t

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from it, the main geologic factors causing the high and stable production of these wells still puzzle the researcher. Under the special geologic background of low organic carbon abundance of source rocks and highly densified and heterogeneous reservoirs, the exploration direction of the tight oil in the Da'anzhai Member of the Sichuan Basin remains murky. In view of the above problems, in this study, we have looked closely into the main factors contributing to the high and stable production of the Da'anzhai Member tight oil reservoirs by sorting out huge amounts of exploration and development data, in the hope of making out the direction of next step exploration and development of the Da'anzhai Member, and promoting the exploration and scale development of the Jurassic tight oil in the Sichuan Basin[4–8].

2. Geological characteristics of tight oil

2.1. Large resources and low abundance

The Jurassic Da'anzhai Member in the Sichuan Basin is freshwater lake facies deposits. During the Da'anzhai period, the lake basin experienced three stages of evolution, lake transgression, the largest lake and lake retreat. According to lithological combination, electric property and sedimentary cycle characteristics, the Da'anzhai Member can be divided into three sub-members, Da_1, Da_1^3 and Da_3. The Da_1^3 sub-member deposited in the largest lake flooding period is shallow lake – semi-deep lake shale. With a thickness of 30–60 m, and total organic carbon content (TOC) of 0.10%–4.27%, 1.15 % on average, it is medium-good hydrocarbon source rock. The source rock has sapropelic kerogen, and organic vitrinite reflectance between 0.8% and 1.4%. With the increase of burial depth from south to north, the shale of the Da'anzhai Member is increasing in organic matter maturity, and has reached oil generation peak in most of the area. According to the results of the fourth resources evaluation of petroleum in China, the resources of the Jurassic tight oil in the Sichuan Basin amount to 16×10^8 t, ranking the fifth in China, in which Da'anzhai Member has tight oil resources of over 9.78×10^8 t, accounting for 60.6% of the resources of the Jurassic, demonstrating huge potential for exploration and development. But compared with other tight oil plays, the resource abundance of the tight oil in Jurassic in the basin is only $(3–10) \times 10^4$ t/km^2, much lower than other tight oil basins[9–12] (Table 1).

Table 1. Statistics on tight oil resources of basins in China

Basin	Horizon	Geological resources/10^8 t	Abundance of geological resource/(10^4 t·km^{-2})
Songliao	K_{1+2}	24.43	13–19
Santanghu	P_2l, P_2t	17.28	48
Bohai Bay	E	16.40–17.10	8–52
Sichuan	J_{1+2}	16.11	3–10
Qaidam	E—N	6.6–7.2	20
Junggar	P_2l	6.62	48
Erlian	K_1	3.64	23
Tuha	J_{1+2}	3.40	6.2
Fushan sag	E_2	0.80	23
Huahai	K_1	0.54	15
Sanshui	E_1	0.45	15
Jiuxi	K_1	0.07	67

2.2. Relatively high quality reservoirs

The main reservoirs of the Da'anzhai Member are shell limestone and clay-shell limestone. They are mostly in the Da_1 and Da_3 sub-members, generally 2–5 m thick in single layers, some more than 20 m thick; 10–30 m, up to 40 m thick cumulatively. The reservoirs have a porosity range of 0.5%–2.0 %, an average porosity of only 1.06%, and permeability of less than 0.1×10^{-3} μm^2, high densification degree, strong heterogeneity, and fast vertical and horizontal change, representing extremely low porosity tight reservoirs. Analysis of thin section, scanning electron microscopy and CT scan shows that the reservoir space is made up of dissolution vug, pore and fracture of various types, including multi-level fracture + dissolution vug and pore, multi-level + intercrystalline and intracrystalline fracture dissolution vug and pore (the combination of vugs, pores and fractures of different scales in space). In general, the main reservoir space is composed of micro- and nano-pores and throats (according to the analysis of the parameters of pressure mercury curve, the lower limit of oil charging of 32 nm was substituted into the regression formula of mercury porosity and throat median radius, and the porosity lower limit calculated was 1.5%, so the relative high quality reservoirs were defined as reservoirs with porosity of greater than 1.5%), but most pores and throats of the reservoirs are in the nano-micron range (Table 2, Fig. 2). Relatively high quality reservoirs are concentrated in the Da_1 sub-member vertically, and in the southern part of Sichuan on the plane.

Table 2. Pore structure characteristics of the Jurassic Da'anzhai Member in central Sichuan Basin

Pore scale	Pore radius/μm	Pore type	Development degree	Lithology
Big pore	100–1000	Intragranular dissolved pore, intergranular dissolved pore	Low	Shell limestone
Medium pore	10–100	Intragranular pore, intergranular pore	Low	Clay - shell limestone
Micro-pore	1–10	Intragranular pore	Fairly high	Clay - shell limestone, shell limestone
Nano-pore	0.001–1	Intracrystalline pore, intercrystalline solution pores	High	Clay - shell limestone, shell limestone

2.3. Sources are reservoirs (or in close contact) conducive to oil and gas migration and accumulation

The charge of tight oil is a process in which oil is squeezed