

Research article

Accumulation conditions and enrichment patterns of natural gas in the Lower Cambrian Longwangmiao Fm reservoirs of the Leshan-Longnǔsi Palaeohigh, Sichuan Basin

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Abstract

As several major new gas discoveries have been made recently in the Lower Cambrian Longwangmiao Fm reservoirs in the Leshan-Longnǔsi Palaeohigh of the Sichuan Basin, a super-huge gas reservoir group with multiple gas pay zones vertically and cluster reservoirs laterally is unfolding in the east segment of the palaeohigh. Study shows that the large-scale enrichment and accumulation of natural gas benefits from the good reservoir-forming conditions, including: (1) multiple sets of source rocks vertically, among which, the high-quality Lower Paleozoic source rocks are widespread, and have a hydrocarbon kitchen at the structural high of the Palaeohigh, providing favorable conditions for gas accumulation near the source; (2) three sets of good-quality reservoirs, namely, the porous-vuggy dolomite reservoirs of mound-shoal facies in the 2nd and 4th members of the Sinian Dengying Fm as well as the porous dolomite reservoirs of arene-shoal facies in the Lower Cambrian Longwangmiao Fm, are thick and wide in distribution; (3) structural, lithological and compound traps developed in the setting of large nose-like uplift provide favorable space for hydrocarbon accumulation. It is concluded that the inheritance development of the Palaeohigh and its favorable timing configuration with source rock evolution are critical factors for the extensive enrichment of gas in the Lower Cambrian Longwangmiao Fm reservoirs. The structural high of the Palaeohigh is the favorable area for gas accumulation. The inherited structural, stratigraphic and lithological traps are the favorable sites for gas enrichment. The areas where present structures and ancient structures overlap are the sweet-spots of gas accumulation.

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Keywords: Sichuan Basin; Leshan-Longnǔsi Palaeohigh; Sinian-Early Cambrian; Hydrocarbon accumulation; Sweet spot; Source rock; Structural adjustment

1. Introduction

Discovered at the beginning of 1970s in the Sichuan Basin, the Leshan-Longnǔsi Palaeohigh is a large nose-like synsedimentary and denuded Palaeohigh that was developed in Early Cambrian and fell into a pattern in Pre-Permian [1], with the axial line starting from Leshan in the west and

terminating at Longnǔsi in the east. Calculated by the full denuded area of Silurian, the area of the Palaeohigh is 6.25×10^4 km². The exploration of the Sinian-Lower Palaeozoic in the Leshan-Longnǔsi Palaeohigh commencing in 1950s, resulted in the discovery of the first integral large gas field in China – Weiyuan gas field in 1964 on the slope at southwest flank of the Palaeohigh, where Sinian Dengying Fm is the major pay. But after that, although the Sinian-Lower Palaeozoic of the Palaeohigh had been the key point of concern and under constant exploration, no major discovery had been made until 2010 (Fig. 1).

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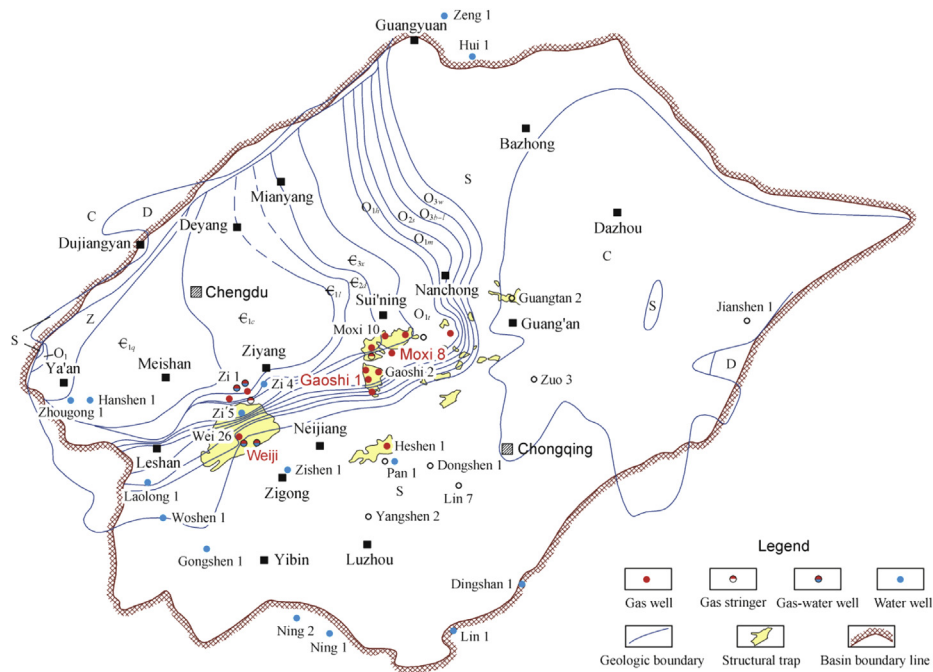


Fig. 1. Pre-Permian palaeogeologic map and distribution of Sinian-Lower Palaeozoic gas and water wells in the Sichuan Basin.

Well Gaoshi 1 in the east segment of the Palaeohigh tested a gas flow of $102 \times 10^4 \text{ m}^3$ a day in the 2nd member of the Sinian Dengying Fm in July 2011; later, Well Moxi 8 tapped a gas flow of $191 \times 10^4 \text{ m}^3$ per day in the two sets of reservoirs in the Lower Cambrian Longwangmiao Fm in September 2012. To this point, after strenuous efforts, the petroleum exploration of the Sinian-Lower Palaeozoic in the Leshan-Longnūsi Palaeohigh finally harvested the major discovery in Sinian and historical breakthrough in the Cambrian Longwangmiao Fm, forerunning the new page of Sinian-Lower Palaeozoic exploration in the Palaeohigh. With the rapid and efficient exploration in the past two years, a super-huge gas reservoir group with multiple gas pay zones vertically and cluster pools in the plane is unfolding in the east segment of the Palaeohigh, where the proved gas reserves have exceeded $4400 \times 10^8 \text{ m}^3$.

2. Good geologic conditions for gas accumulation in Sinian-Cambrian

2.1. Good hydrocarbon source conditions represented by multiple sets of source rocks

There developed multiple sets of source rocks of two categories in the Sinian-Cambrian of the Sichuan Basin, mud shale category including Sinian Doushantuo Fm mudstone, Deng III member mudstone, Cambrian Qiongzhusi Fm shale and Canglangpu Fm mudstone; carbonate category includes Dengying Fm argillaceous dolomite. Among them, Doushantuo Fm mudstone, Deng III member mudstone and Qiongzhusi Fm shale have higher abundance, with an average TOC of 2.06%, 1.19% and 1.88% (Table 1) respectively, and are in high-overmature stage; whereas the average TOC of

Canglangpu Fm mudstone and Dengying Fm argillaceous dolomite is only 0.91% and 0.61% respectively.

The Sinian-Cambrian source rocks are thick, and premium source rocks are widespread across the basin. The Lower Cambrian argillaceous source rocks are 140 m thick on average, and $15 \times 10^4 \text{ km}^2$ in area in the basin (Fig. 2); Sinian Deng III member mudstone, 10–30 m thick, covers an area of $7 \times 10^4 \text{ km}^2$ in the basin; while Doushantuo Fm mudstone, 10–30 m, covers an area of $5 \times 10^4 \text{ km}^2$ in the basin. Apart from large distribution area, the hydrocarbon generation intensity and quantity of source rocks are also large.

Taking Lower Cambrian argillaceous source rocks as an example, the hydrocarbon generation intensity ranges from 0 to $160 \times 10^8 \text{ m}^3/\text{km}^2$, 40×10^8 – $45 \times 10^8 \text{ m}^3/\text{km}^2$ on average (Fig. 3). More importantly, Cambrian source rocks are very thick at the structural high of the Palaeohigh, especially, the Lower Cambrian argillaceous source rocks on the west side of Gaoshiti, with an average thickness of 400 m and gas generation intensity of $140 \times 10^8 \text{ m}^3/\text{km}^2$, providing good source conditions for the formation of near-source gas reservoirs in the Palaeohigh area.

Table 1

Statistics on the organic carbon content of Sinian-Cambrian source rocks in the Sichuan Basin and its peripheral areas.

Horizon	Stratigraphy and lithology	TOC	R_o
Cambrian	Canglangpu Fm mudstone	0.51%–1.56%/0.91%	/
	Qiongzhusi Fm shale	0.50%–7.56%/1.88%	1.83%–3.90%
Sinian	Deng III member mudstone	0.50%–4.73%/1.19%	3.16%–3.21%
	Dengying Fm argillaceous dolomite	0.20%–3.67%/0.61%	1.97%–3.46%
	Doushantuo Fm mudstone	0.56%–4.64%/2.06%	2.08%–3.82%

Note: For TOC the figures before and after the N-dash stand for range value, while those after the oblique line stand for average value.

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