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RESEARCH PAPER

Key controls on accumulation and high production of large non-marine gas fields in northern Sichuan Basin

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Abstract: Based on the data from multiple sample analysis and tests and exploration practice, key factors controlling gas accumulation, enrichment and high production in the continental Triassic Xujiahe–Jurassic Ziliujing formations in Yuanba, Tongnanba and other areas, northern Sichuan Basin, were discussed. Natural gas in continental strata in this part of the basin are derived from the source rocks in the same strata, which are good - very good source rocks with high abundance of organic matter (mostly type III) and generally in high mature – overmature gas generating stage. Depending on provenance, multi-period (fan) delta systems are developed in the research area, where the main fluvial channel sands are superimposed in multi periods and distributed extensively, and reservoirs and source rocks form the "lower generation and upper storage" and "inter-bedded" assemblages. Five typical high-yield wells in the Jiulongshan, Malubei and Yuanba areas are investigated and an overall concept for exploration and research in the area is proposed: sedimentary source controls rock types, cementation types and sedimentary microfacies; source rocks control the size and location of gas accumulation; structural types control the magnitude and location of fractures; the combination of fracture and reservoir determines the level and retention duration of gas production. According to this model, the following areas have enriched gas and high production: Xu-3 and Xu-4 members of Xujiahe Formation in the western Yuanba and Jiange, Xu-4 member and Ziliujing Formation in the mid-eastern Yuanba, Zhenzhuchong and Xu-2 members in Malubei and Hebachang areas in the Tongnanba structure.

Key words: enrichment and high production; non-marine strata; northern Sichuan Basin; Yuanba area; Tongnanba area; gas field

1 Introduction

The northern Sichuan Basin, which has undergone the Jinning, Caledonian, Hercynian, Indosinian, Yanshan and Himalayan movements, is bounded by Micangshan uplift to the north, Dabashan front nappe to the northeast, and its terrain gradually changes to medium-low structure belt to the south (Fig.1). The tectonic framework, including two main structures oriented NW and NE, and some others trending NNE, NWW, SN, etc., was formed by stresses from the directions Xuefengshan, Dabashan, Micangshan and Longmenshan in different periods, as a result of the joint action of multi-episode tectonic movements.

The Xujiahe gas field (with the proved reserves of 191×10^8 m^3) of continental facies was discovered in Malubei after the Puguang, Yuanba, Longgang marine gas fields were found in the northern Sichuan Basin. In the recent two years, gas exploration breakthroughs have been achieved in some formations, such as Triassic Xujiahe Formation, and Jurrasic Ziliujing Formation in the Jiulongshan, Yuanba, Jian'ge, and Longgang areas[1]. High-yield commercial gas flow has been encountered in several wells from continental sequences, suggesting that the continental strata in the northern Sichuan Basin have the geological conditions of forming giant gas fields and a significant exploration potential.

Based on analyses and tests on a large number of samples, as well as exploration practice, we discuss the key factors that

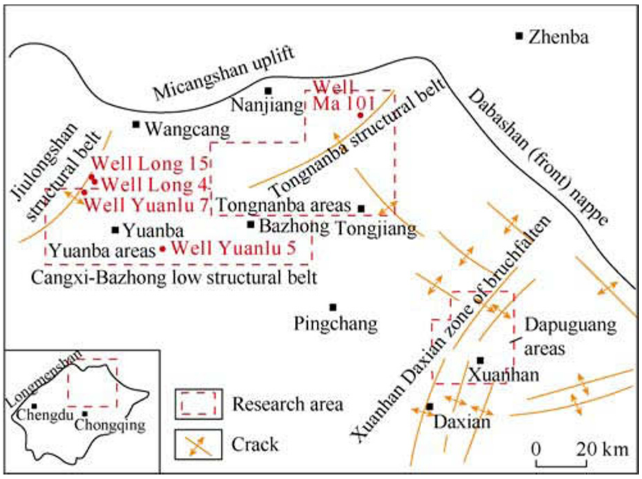

Fig. 1 Structural locations in the Yuanba, Tongnanba, Dapuguang areas in the northern Sichuan Basin

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control gas accumulation, enrichment and high-production in continental Xujiahe Formation – Ziliujing Formation in Yuanba, Tongnan and some other areas in the northern Sichuan Basin to provide scientific basis for future exploration.

2 Geological conditions to form large continental gas fields

2.1 Source rock horizon

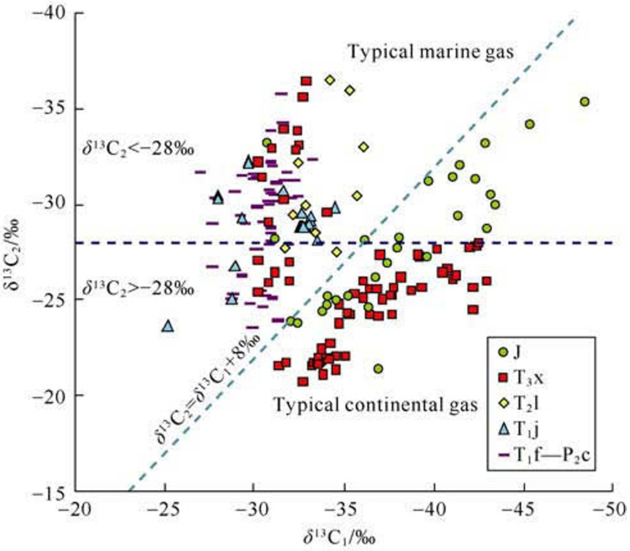
The carbon isotope composition of marine and continental methane, ethane in the Sichuan Basin has regular distribution (Fig. 2) [1]. On $\delta^{13}C_1$ and $\delta^{13}C_2$ distribution plot, the carbon isotope composition of the gas from upper Triassic Xujiahe Formation (T_3x) and Jurassic is mainly located below the line $\delta^{13}C_2=\delta^{13}C_1+8‰$ (Fig.2). There are obvious differences between the ethane carbon isotope composition in the gas from Xujiahe Formation and from the Jurassic, indicating different organic matter sources (Fig.2). However, there are also a few $\delta^{13}C_1$ and $\delta^{13}C_2$ values showing features of non-continental gas, scattered in marine gas distribution part. These continental gas samples with abnormal carbon isotope composition were collected from the northern or southeastern Sichuan Basin where lower marine gas migrated upwards along faults.

The carbon isotope composition of the gas source rock kerogen is about 1‰ heavier than that of gas butane it generated[2]. Butane carbon isotope was not observed in the gas from Jurassic Qianfoya Formation, Yuanba area (J_2q). According to the carbon isotope variation trend of alkane gas, it is 1‰–2‰ heavier in butane than in propane, so the value of $\delta^{13}C_4$ is estimated at –27‰– –26‰. In the Qianfoya Formation in the study area, $\delta^{13}C$ of hydrocarbon source rock kerogen is –27.0‰– –23.3‰, with the average value of the 6 samples of –25.4‰. It is 1‰ heavier than the estimated $\delta^{13}C_4$ value above, indicating that the gas was from source rock in the same sequence (Fig. 3a).

The gas carbon isotope composition of Jurassic Ziliujing Formation (J_1z) varies within a certain range, the $\delta^{13}C$ values of C_1—C_4 are –42.2‰– –29.5‰, –28.2‰– –21.4‰, –29.0‰– –21.5‰ and –21.6‰– –20.8‰, respectively. The carbon isotope composition of butane tends to be heavier (so do ethane and propane). The $\delta^{13}C$ value for gas source rock kerogen should be –21‰– –20‰ based on the above mentioned gas-source rock carbon isotope relation. However, source rocks with so heavy carbon isotope composition were not developed in the Sichuan Basin: kerogen $\delta^{13}C$ in Ziliujing Formation in this area is 25.9‰– –22.5‰, with –24.0‰ on average for the 10 samples. Based on the whole variation tendency of gas carbon isotope composition, as well as the factors mentioned above, it is believed that Ziliujing Formation gas has a close relationship with source rock in the same sequence (Fig.3b), and the much heavier C_2—C_4 carbon isotope composition was caused by carbon isotope re-fractionation resulted from secondary cracking of heavy hydrocarbon gas in the high thermal evolution period of Ziliujing Formation source rock.

The Xujiahe Formation gas in the Yuanba area was also from source rock in the same sequence. Affected by secondary cracking of heavy hydrocarbon gas and mixed source, the distribution pattern of alkane gas $\delta^{13}C$ is evidently different from that of the overlying Jurassic gas (Fig.3c).

In conclusion, there are obvious differences in alkane carbon isotope composition and distribution pattern between the Qianfoya Formation, Ziliujing Formation and Xujiahe Forma-



T_3x—Upper Triassic Xujiahe Formation; T_2l—Middle Triassic Leikoupo Formation; T_1j—Lower Triassic Jialingjiang Formation; T_1f—Lower Triassic Feixianguan Formation; P_2c—Upper Triassic Changxing Formation

Fig. 2 Methane and ethane carbon isotope distribution of typical marine and continental gas from the Sichuan Basin

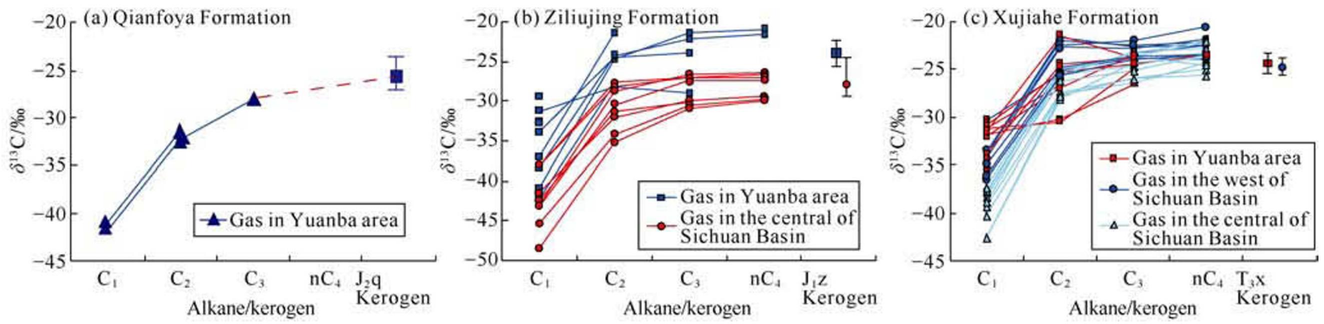


Fig. 3 Carbon isotope composition of continental gas alkane and source rocks in the Sichuan Basin