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Geochemical evidence for in situ accumulation of tight gas in the Xujiahe Formation coal measures in the central Sichuan Basin, China

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ABSTRACT

The study of accumulation mechanisms of tight gas has attracted much attention in recent years. One of the focuses is whether natural gas can migrate on a large scale in tight reservoirs. In this work, geochemical parameters (such as C_1/C_{1+}, $C_1/(C_2+C_3)$, C_{1+}, $\delta^{13}C_1$, $\delta^{13}C_2$, iC_4/nC_4, iC_5/nC_5) of the tight gas reservoirs in the central Sichuan Basin, China have been studied to characterize the accumulation mechanisms in these fields. Results show that the tight gas accumulation in the Xujiahe Formation in the central Sichuan is in situ, and natural gas has not experienced large-scale migration. In gases from the central Sichuan Basin, $\delta^{13}C_1$ ranges from −44.1‰ to −37.1‰ with an average of −40.1‰, and C_1/C_{1+} ranges from 0.80 to 0.97 with an average of 0.91. While in the gases from the western Sichuan Basin, $\delta^{13}C_1$ is between −35.5‰ and − 30‰ with an average of −32.2‰, and C_1/C_{1+} ranges from 0.95to 0.99with an average of 0.98. Based on geochemical indicators of natural gas, the gases of Xujiahe Formation in the Central Sichuan Basin originated from the local coal measures of the Xujiahe Formation in horizontal direction with little contribution from the western Sichuan. In central Sichuan Basin, there is also no horizontal migration of natural gas in the same formation between adjacent gas fields. Vertically, the Xujiahe Formation is an independent gas generating system and has no relationship with the underlying Mid-Lower Triassic formations and the Jurassic natural gas formation above it. The $\delta^{13}C_2$of Xujiahe Formation in central Sichuan ranges from −28.3‰ to −25.9‰, with an average of −27.5‰. However, the $\delta^{13}C_2$ of Lower Jurassic above Xujiahe Formation ranges from −36.8‰ to −30.5‰, with an average of −33.0‰. Under the Xujiahe Formation, the $\delta^{13}C_2$ in Leikoupo Formation ranges from −35.5‰ to −32.1‰, with an average of −33.1‰, and in Jialingjiang Formation ranges from −34.6‰ to −33.2‰, with an average of −33.8‰. There is also a clear distinction in the geochemical characteristics of natural gas between the upper and lower gas reservoirs in the Xujiahe Formation, indicating that there is no obvious vertical migration of natural gas. Geochemical evidence shows that there is no large-scale gas migration in the Xujiahe Formation. The tight gas is generated in situ and accumulated in the formation in the central Sichuan Basin.

1. Introduction

With the development of oil and gas exploration technologies, unconventional oil and gas have become the center of focus. In China, tight oil and gas exploration is currently under fast development as a potential oil and gas resources (Jia et al., 2012). Many tight gas fields have been found in Sichuan Basin, Ordos Basin and Tarim Basin in China, and the proven reserves and annual production of tight gas has been increasing with time (Dai et al., 2012a). Together with the unconventional oil and gas exploration, some issues have arisen. Among them, the accumulation mechanisms of tight gas have drawn huge attention. Previous research on the formation of tight gas mainly focused on the evolution of geological conditions in tight gas reservoirs (Che et al., 2007; Bian et al., 2009; Tong et al., 2012; Chen et al., 2014; Wei et al., 2016; Wei et al., 2017), formation characterization (Xie et al., 2009) and reservoir geochemistry (Xiao et al., 2008; Dai et al., 2012a,b; Wu et al., 2017). Representative documents related to tight gas accumulation internationally include the concept of continuous oil and gas accumulation proposed by Gautier and Mast, 1995. The reservoir is a gas field group that is not strongly affected by the water column, and the gas enrichment is not directly related to the buoyancy of the gas to the gas. Many years later,two simplified models of tight sandstone gas reservoir have been summarized as the continuous basin-centered gas accumulation, characterized saturated gas interval in the deeper parts

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of the basin with gas-water inversion, and the gas accumulation in subtle conventional stratigraphic and structural traps with gas charge driven by buoyancy (Fall et al., 2012). However, few literatures have discussed the possibility of large-scale migration of natural gas in tight sandstone reservoirs. The use of natural gas geochemical parameters to study the migration of natural gas in tight sandstones is fairly rare. It is unclear if the natural gas in the tight gas reservoir is generated and accumulated in situ or migrated over a long distance or migrated from sources close to a reservoir. In view of these research questions, this paper takes the coal derived tight gas reservoir in the Xujiahe Formation in the central Sichuan Basin as the study site. The aim is to understand the accumulation processes associated with this tight gas reservoir by characterizing the geochemistry of the natural gas in the reservoir.

The Xujiahe Formation in the Sichuan Basin is mainly composed of a set of coal deposits originated from fluvial, lacustrine and swamp facies (Yang et al., 2009; Xu et al., 2009). It is the first continental strata formation after evolution of the Sichuan Basin from marine facies to continental facies. It is commonly developed in the entire Sichuan Basin. The formation experienced multiple sedimentary cycles and developed into multiple sets of coal measures interbedded with multiple sets of tight sandstones overlapping each other. Due to the fact that the depositional center of Xujiahe Formation is in the western part of the Sichuan Basin, the thickness of coal-bearing source rocks gradually decreases from the west towards the central Sichuan Basin (Liu et al., 2005; Chen et al., 2007; Yang et al., 2010), the gas generation intensity of the Xujiahe Formation coal-bearing source rocks is relatively low, less than $20 \times 10^8\ m^3/km^2$ in most areas (Fig. 1). This value is the minimum gas-generating intensity to form a reserve of $100 \times 10^8\ m^3$ in China (Dai et al., 1997). Based on past exploration experience, such a low gas intensity is unlikely to form a large gas field with a reserve of $1000 \times 10^8\ m^3$. Although the gas intensity is low, but so far a number of large-scale gas fields with proven reserves exceeding $1000 \times 10^8\ m^3$ have been discovered in the Xujiahe Formation in the central Sichuan Basin, such as the Xujiahe reservoir in the Anyue gas field, Guang'an gas field, Hechuan gas field, and a series of small and medium gas fields. Some researchers suggested that natural gas in the Xujiahe Formation reservoirs in the central Sichuan Basin mainly comes from the western Sichuan Basin and that the natural gas generated from the thick coal-bearing source rocks in the Xujiahe Formation in the western Sichuan has laterally migrated long distances to the central Sichuan Basin. Others proposed that the Xujiahe Formation in the central Sichuan Basin could migrate only short distance because of the strong heterogeneity of the reservoir and the relatively gentle strata (Jiang et al., 2006; Zhao et al., 2011). However there is a lack of geochemical evidence for both hypotheses. There is also a view that the Xujiahe Formation gas reservoir is a “continuous” lithologic gas reservoir formed by evaporative hydrocarbon expulsion of coal-bearing source rocks in a large area (Zou et al., 2009; Yi et al., 2013). It is also suggested that natural gas in the Xujiahe Formation in the central Sichuan Basin is not “large-area contiguous” but dispersed into discrete sheet-type reservoirs (Zhao et al., 2010).

To distinguish between the in-situ and near-field accumulation mechanisms of natural gas in the Xujiahe Formation in the central Sichuan Basin, natural gas migration parameters, such as the dryness coefficient of natural gas, isotopic values of methane and enthane, the ratio of iC_4/nC_4 etc., are used in this study. Results show that natural gas in the Xujiahe Formation originates from coal-bearing source rocks in the Xujiahe Formation itself, with little contribution from other sources. The possibility of natural gas coming from the Xujiahe Formation source rock in the western Sichuan Depression has been ruled out. Horizontal and vertical connectivity between the gas reservoirs in different sections in the Xujiahe Formation in the central Sichuan Basin have also been studied using gas geochemical approaches.

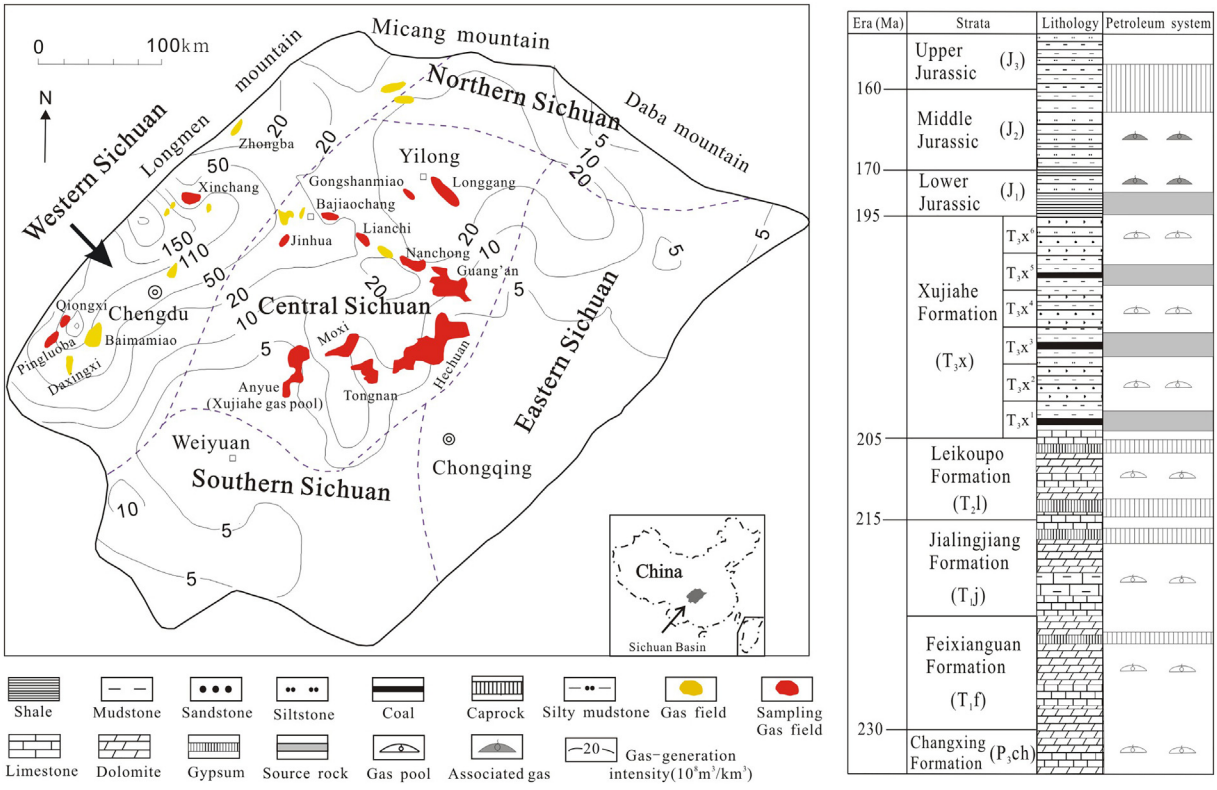

Fig. 1. Map of gas field distribution in Xujiahe Formation and stratigraphic column in the central Sichuan Basin.