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Geochemistry of Tight Sandstone Gas in Upper Triassic Xujiahe Formation in Central Sichuan Basin*

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The Sichuan Basin is an inner plate basin at the west of Yangzi Plate. It lies at the east of Longmen Mountain- Ermei Mountain- Daliang Mountain, occupying the whole eastern Sichuan province and Chongqing city. The Sichuan Basin is a large petroliferous basin with marine carbonate deposition and terrestrial clastic deposition (Guo et al., 1996; Tong et al., 1992; Dai et al., 1997). Several large gas fields, i.e., Bajiaochang, Tongnan, Guang'an, Hechuan, Anyue gas field, and a series of small gas fields, i.e., Jinhua, Moxi, Suinan, Chongxi, Lianchi and Longnvci gas field have been discovered since the Xuejiahe Formation exploration in Chuanzhong area 60 years ago (Fig. 1). The proven reserve of the Chuanzhong area has exceeded 500 trillion cubic meters. Natural gas in Xuejiahe formation of Upper Triassic in Chuanzhong area shows great exploration potential.

1. Geological conditions of natural gas

Xujiahe Formation in the Sichuan Basin was formed in the transient period from Late Triassic marine craton to terrestrial basin, and was upwardly composed by marine→marine-terrestrial alternating→terrestrial facies, which were dominated by the terrestrial coal-bearing clastic assemblage. The formation thickness is 2000~4000m, and is the thickest in western Sichuan Basin, and the formation tends to be wedge and fan-shaped thinner towards east. The formation can be vertically divided into six members, and the first, third and fifth members are dominated by coal-bearing mud shales as the main source rocks, while the second, fourth and sixth members consist mainly of sandstones as the main reservoirs. Therefore, three sets of source-reservoir-seal assemblages developed vertically, forming favorable sandwich-type reservoir-forming assemblages with both source and reservoir in the formation.

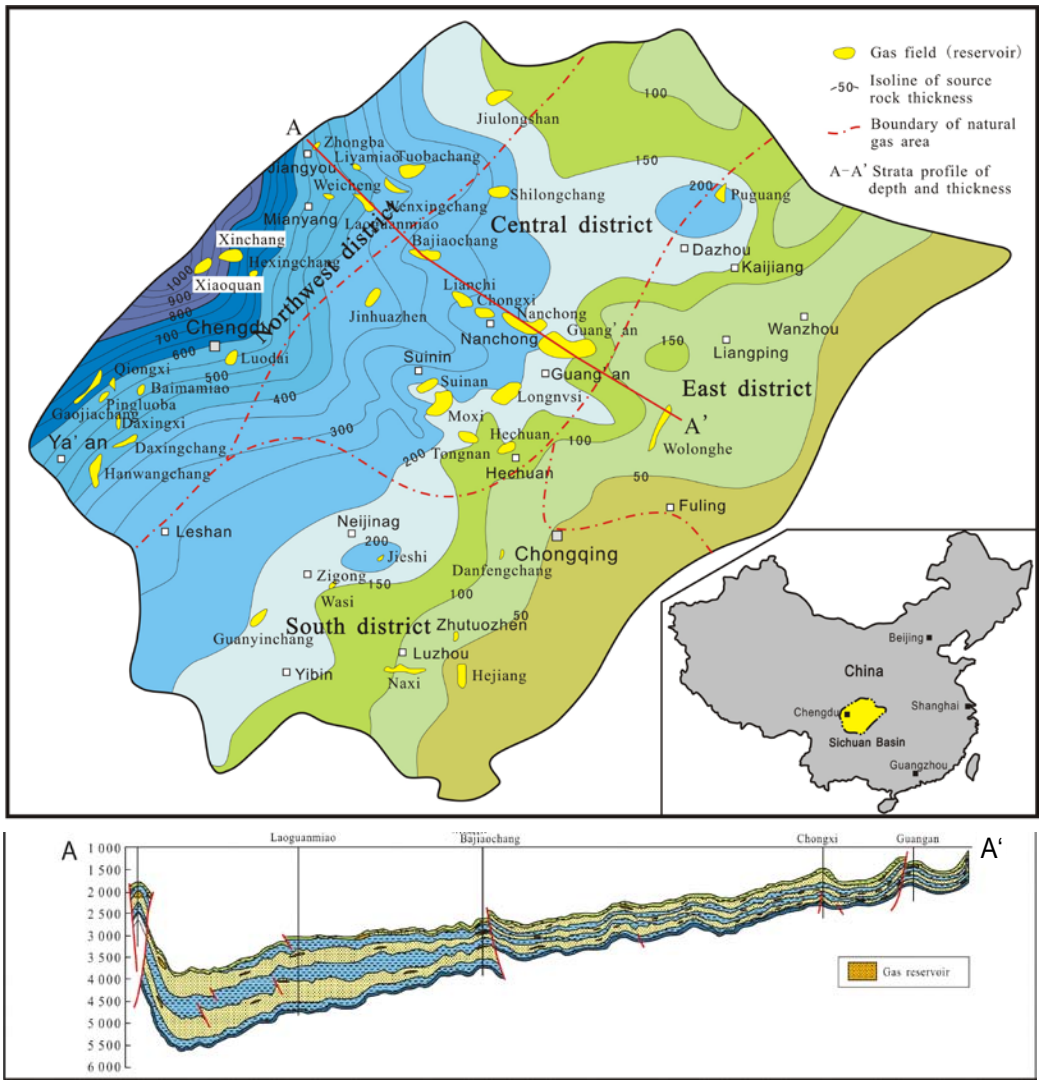

Fig. 1: The distribution of the Xujiahe Formation source rock and gas fields in the Sichuan Basin(Dai et al., 2009)

1.1 Characteristics of hydrocarbon source rocks

II_2 and III-type coal-bearing hydrocarbon source rocks with fluvial-swamp and lacustrine-swamp facies developed in the first, third and fifth members in Xujiahe Formation in central-west Sichuan Basin. The TOC of dark sandstone in Xujiahe Formation is 0.24%~4.99, mainly 0.5%~1.7% with 1.18% in average. Type II_2 and III kerogen equivalent to the oil window (Ro=0.7~1.3%) generates mainly gas assisted with oil in the early-middle stage of coal-forming process. Ro of source rocks in central Sichuan Basin is 0.8%~1.5%, indicating the early mature-high mature stage, and gas rather than oil are generally discovered. For example, more than 90% of the wells in Guang'an and Hechuan gas fields produce only gas, with few ones produce oil. The gas/oil ratio of several wells producing gas assisted with condensate oil is as high as 150~4600.

1.2 Characteristics of reservoir rocks

The reservoir rocks in the second, fourth and sixth members of Xujiahe Formation in Sichuan Basin are mainly a set of terrestrial clastic rocks with low composition maturity and high structure maturity. The reservoir types are mainly fissure-pore and pore. According to the analysis of over 36000 samples, the average porosity of Xujiahe Formation reservoirs is 4.77%, with 0.10% and 18.27% as the minimum and maximum values respectively; The average permeability is $0.19\times10^{-3}\mu m^2$, with$0.001\times10^{-3}\mu m^2$ and $50\times10^{-3}\mu m^2$ as the minimum and maximum values respectively. As a whole, the reservoirs are tight sandstone ones with bad property, and a few reservoirs with middle-porosity and low-permeability developed locally.

1.3 Characteristics of cap rocks

Upper Triassic Xujiahe Formation in Sichuan Basin were mainly buried underground, and the burial depth became deeper from central to west Sichuan Basin varying from 2000 to 5000m, and the mud shales in the third and fifth members of Xujiahe Formation and the overlying thick Jurassic muddy layer could closely cap with favorable preserving conditions.

1.4 Characteristics of gas reservoirs in Xujiahe Formation

The gas reservoir in Xujiahe Formation are with different types, including tight gas reservoir in foredeep depression, lithological entrapment gas reservoir in foreland slope and diagenetic entrapment gas reservoir. The water saturation of the gas pools are relatively high with complex gas-water relationship. The distribution and enrichment of the gas pools are influenced commonly by source rocks, favorable reservoirs, local uprise and faults.

2. Natural gas geochemistry

2.1 The composition and carbon isotope values of natural gas

CH_4 dominates the hydrocarbon component of gas in Xujiahe Formation, and the content of C_2^+ is high. The gas is a kind of kerogen thermal degradation gas and most of dry indexes are less than 0.95, indicating it is a kind of wet gas (Fig.2). There is no H_2S in the gas, and there is no the mixture of oil and gas from underlay marine stratum. In gas fields of Xujiahe Formation, $\delta^{13}C_1$ ranges from -44‰ to -33‰, $\delta^{13}C_2$ ranges from -29‰ to -25‰, $\delta^{13}C_3$ ranges from -28‰ to -23‰, and $\delta^{13}C_4$ ranges from -27‰ to -21‰. The difference between $\delta^{13}C_1$ values and $\delta^{13}C_2$ values are commonly as high as more than 10% with heavy ethane carbon isotope, showing the characteristic of coalifeous gas. It indicates that the natural gas in Xujiahe Formation is from coal series source rocks of Upper Triassic, without contribution from deep source rocks (Dai et al., 2007a, 2007b; Volk et al., 2004; Dai et al., 2009; Liu et al., 2000). Carbon isotope of carbon dioxide is -5.6 ‰ ~ -15.6 ‰, indicating the coexistence of organic and inorganic genesis. Inorganic carbon dioxide came from the sedimentary rocks and formation water of crust layer.

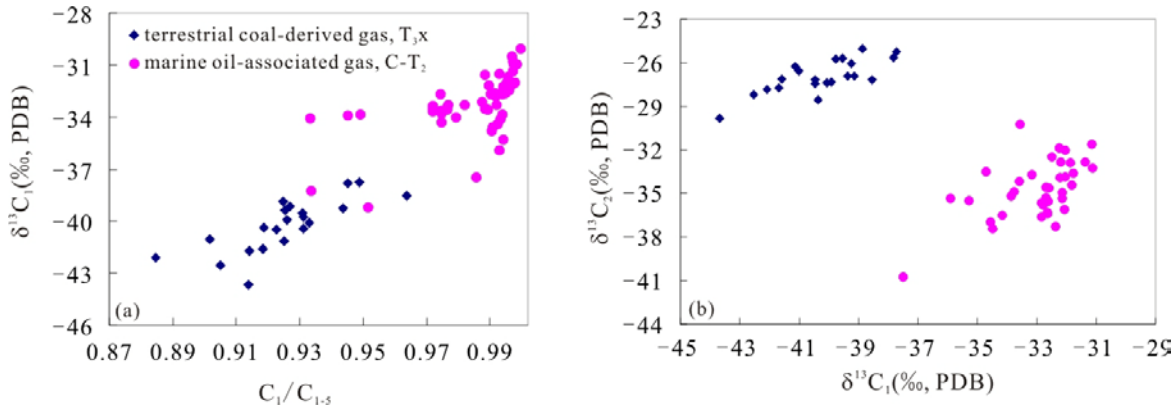

Fig.2: $\delta^{13}C_1$-C_{1-5}(a) and $\delta^{13}C_2$-$\delta^{13}C_1$(b) diagrams of Xujiahe Formation-reservoired natural gas in central Sichuan Basin(The data of C-T_2 is from Dai Jinxing)

The methane carbon isotope of Xujiahe Formation-reservoired natural gas becomes heavier as the dryness index increases, and they are positively correlated(Fig.2a). The dryness index of the gas in central Sichuan Basin ranges from 0.86 to 0.96, and the carbon isotope of natural gas derived from humic source rocks is heavier than that from sapropelic ones. The carbon isotope becomes heavier as the maturity increases with the same organic matter type. The $\delta^{13}C_2$ and $\delta^{13}C_1$ values of natural gas reservoired in Xujiahe Formation vary mainly due to the organic matter type and thermal maturity respectively, and they are respectively larger and smaller than those reservoired in marine facies strata(Zhang et al., 2007) (Fig.2).

2.2 He and Ar isotopes of natural gas

The He and Ar associated with natural gas are positively related in content. $^{40}Ar/^{36}Ar$ and $^{3}He/^{4}He$ also has a positive correlation. He and Ar isotopic composition analysis shows that, R / Ra ratio is less than 0.5, the majority of 0.1 or less, reflecting the crust was stable then, there was no deep and large faults or deep-source gas mixs (Dai et al., 1997, 2007b), the natural gas was mainly from the shallow crust.

2.3 Light hydrocarbon compositions of natural gas

In the light hydrocarons of natural gas reservoired in Xujiahe Formation in central Sichuan Basin, the paraffin content varies from 65% to 85%, and the cyclane content is of 15%~30%, while the aromatic hydrocarbon content is less than 10%. Since the aromatic hydrocarbon and cyclane are enriched in ligh hydrocarbon derived from humic matters, those in Xujiahe Formation-reservoired natural gas decrease due to the high content of water. iC_4/nC_4 and iC_5/nC_5 values are well correlated. Vertically, they differentiate insignificantly in natural gas reservoired in the second, fourth and sixth members of Xujiahe Formation, while laterally, they are respectively as low as 0.55~1.43 and 0.73~1.88 in Bajiaochang, Chongxi and Guang'an areas, indicating the short migration distances and local accumulation. Therefore, the i-alkane/n-alkane ratio with the same carbon number grows larger as the migration distance of natural gas increases.

3. Conclusions

CH_4 dominates the hydrocarbon component of gas in Xujiahe Formation, and the content of C_2^+ is high. The gas is mainly derived from kerogen thermal degradation, and most of dry indexes are less than 0.95, indicating a kind of wet gas. There is no H_2S in the gas. The $\delta^{13}C_2$ values are commonly larger than -28‰, indicating the characteristics of coal-derived gas. The natural gas is mainly derived from the Upper Triassic coal-measure source rocks. In Chuanzhong area, Xujiahe Formation has contiguous sand bodies and interbedded source rocks, resulting in favorable combination of source rock, reservoir and cap rock, which is beneficial to continuous gas charge. The wide range of source rock, layered distribution of reservoir and gentle angle of dip, supports the Formation of large scale low-abundance tight sandstone gas field. The gas pools are buried shallowly and favorable for exploration and exploitation.

References

Dai Jinxing, Ni yunyan, Zou Caineng, Tao Shizhen, Hu Guoyi, Hu Anping, Yang Chun, Tao Xiaowan. Stable carbon isotope of alkane gases from the Xujiahe coal measures and implication for gas-source correlation in the Sichuan basin, SW China[J]. Organic Geochemistry. 2009, 40(5):638－646.

Dai Jinxing, Wang Tingbin, Song Yan *et al.* Formation conditions and distribution laws of giant gas fields in China[M]. Beijing: Geological Publishing House. 1997: 184－198.

Dai Jin-xing, Xia Xin-yu, Wei Yan-zhao,. Carbon Isotope Characteristics Of Natural Gas In the Sichuan Basin，China, Petroleum Geology & Experiment [J]. 2001, 23(2): 115-121

Guo Zhengwu, Deng Kangling, Han Yonghui et al. Formation and evolution of Sichuan basin[M]. Beijing: Geological Publishing House, 1996: 80－96.

J. Dai, J. Li, W. Ding, et al. Geochemical characteristics of natural gas at giant accumulations in China. Journal of Petroleum Geology. 2007, 30(3)

Liu Deliang, Song Yan, Xue Aimin et al. Comprehensive research of technology and natural gas accumulation zone in Sichan basin[M]. Beijing, Petroleum Industry Press, 2000.

Tong Chongguang. Tectonic evaluation and hydrocarbon accumulation in Sichuan basin[M]. Beijing: Geological Publishing House, 1992: 5－30.

Volk H, Boreham C, Kempton R H, George S C. Geochemical and compound specific carbon isotopic characterisation of fluid inclusion oils from the offshore Perth Basin (Western Australia): Implications for recognising effective oil source rocks [J]. The Australian Petroleum Production and Exploration Association Journal, 2004, 44(1): 223－239.

Zhang ShuiChang Liang Digang Zhu GuangYou Zhang XingYang Zhang Baomin Chen JianPing Zhang Bin. 2007. Fundamental geological elements for the occurrence of Chinese marine oil and gas accumulations. Chinese Science Bulletin, 52(A01): 28-43

Zou Caineng, Zhang Guangya, Tao Shizhen, et al. The geological characteristics, significant discoveries and unconventional oil geology in oil and gas exploration fields around the world[J]. Petroleum Exploration and Development, 2010, 37(2): 129-145.

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