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Geological Conditions of Tight Sandstone Gas Accumulation by Diffusion in Sulige Gasfield, Ordos Basin, China

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1 Introduction

Tight sandstone gas reservoirs have become the focused field in the global unconventional natural gas exploration and tight sandstone gas output accounts for 75% of the unconventional gas output (Zou et al., 2013). In China, tight sandstone gas reserves and output account for a third of the whole country natural gas reserves and output (Zou et al., 2013). The Sulige gasfield is a typical gasfield with a large amount of tight sandstone gas reservoirs in China and the studies of its Upper Paleozoic tight sandstone gas reservoirs have made a great deal of progresses in the identification and evaluation of source rocks and reservoir rocks, and the analysis of gas reservoirs characteristics, etc. (Liu and Hao, 1996; Fu, 2001; Ma, 2004; Zhang et al., 2009; Liu et al., 2013). However, the reservoir-forming mechanism in the Upper Paleozoic tight sandstone gas reservoirs is not clear because pressure-driven volume flow, as the most important way of forming gas reservoirs, is difficult for gas migration in tight sandstones due to its high capillary force and low driving forces (Wang, 2002; You et al., 2007; Gong et al., 2008; Zhu et al., 2009; Liu et al., 2013). Based on the study of geological conditions and gas reservoir characteristics, we suggest that diffusion could be an important method of gas migration in tight sandstone reservoirs. Gas diffusion can occur spontaneously so long as there is concentration difference even in the tight sandstones because the diameter of gas molecule is much smaller than that of pore and throat in the tight sandstones. Furthermore, diffusion has still been taken as one of important mechanism of gas dissipation (Antonov, 1968; Stklyanin et al., 1968; Pandey et al., 1974; Thompson, 1979; Thomas, 1989; Krooss et al., 1992; Krooss and Leythaeuser, 1996; Fang et al., 2001; Shuai et al., 2004; Liu et al., 2008). Gas diffusion in reservoirs has been mainly studied in the measurement of diffusion coefficients, establishment of numerical diffusive models, calculation of diffusive amount, etc. (Antonov, 1954, 1964; Stklyanin and Litvinova, 1971; Leythaeuser et al., 1982; Krooss and Leythauser, 1988; Hao et al., 1993; Nelson and Simmons, 1995; Fang et al., 2001; Wang and Gao, 2005; Liu et al., 2012). However, there are still many aspects needed to be improved. At least we should know under what* geological conditions gas diffusion can become an alternative mechanism of gas accumulation in tight sandstone reservoirs. This paper provides some favourable geological conditions for gas diffusion in tight sandstone reservoirs of Sulige gasfield, Ordos Basin.

2 Geological Setting

The Ordos Basin is a large cratonic basin with an area of 250,000 km^2 in central China and contains enormous natural gas resources, where five giant gasfields, Sulige gasfield, Yulin gasfield, Wushenqi gasfield, Jingbian gasfield and Daniudi gasfield have been found. The most part of the basin dips gently to the west with an angle of less than 1° and undeveloped faults and folds (Ma, 2004; Xiao et al., 2005; Zhang et al., 2009).

The basin can be divided into six structural units, involving the Yimemg uplift, Weibei uplift, Western edge thrusting belt, Jinxi flexural fold belt, Tianhuan depression and Shanbei slope (Fig. 1). Sulige gasfield is located in the northwest of Shanbei slope and its exploration area is about 2,000 km^2. Sulige gasfield, as the biggest gasfield of China, has so far over 4000×10^8 m^3 proven gas reserves.

3 Geological Conditions of Tight Sandstone Gas Accumulation by Diffusion

3.1 Weak tectonic activities

The conduit systems are usually poorly developed for the weak tectonic activities in the tight gas reservoirs, which makes the gas migration by Darcy flow difficult. However, diffusion can be considered to be an important reservoir-

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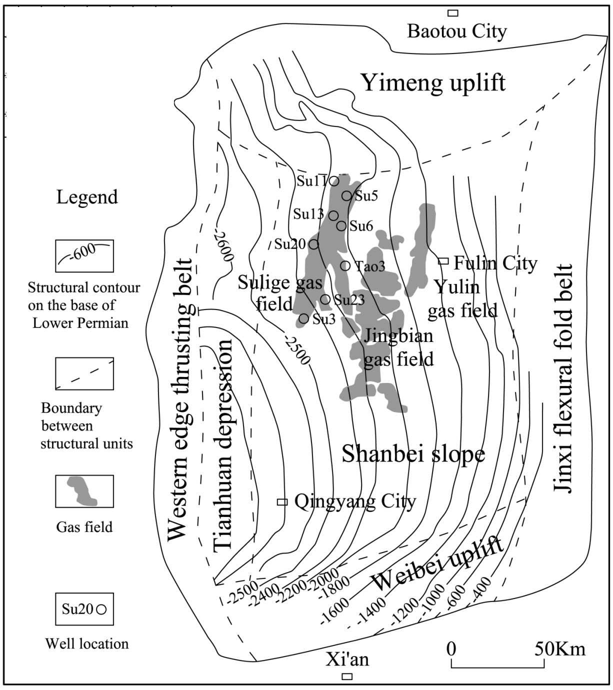

Fig.1. Structural contour map for the base of Lower Permian Shanxi Formation in the Ordos Basin and the location of Sulige gasfield (modified from Zhang et al., 2006).

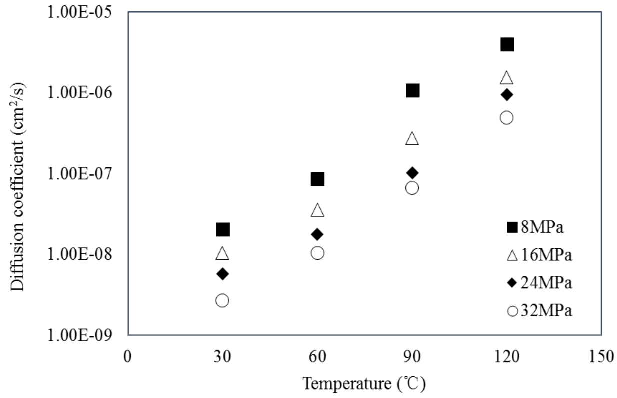

Fig. 2. Plot of methane diffusion coefficient vs. temperature for the tight sandstone in Sulige gasfield, Ordos Basin.

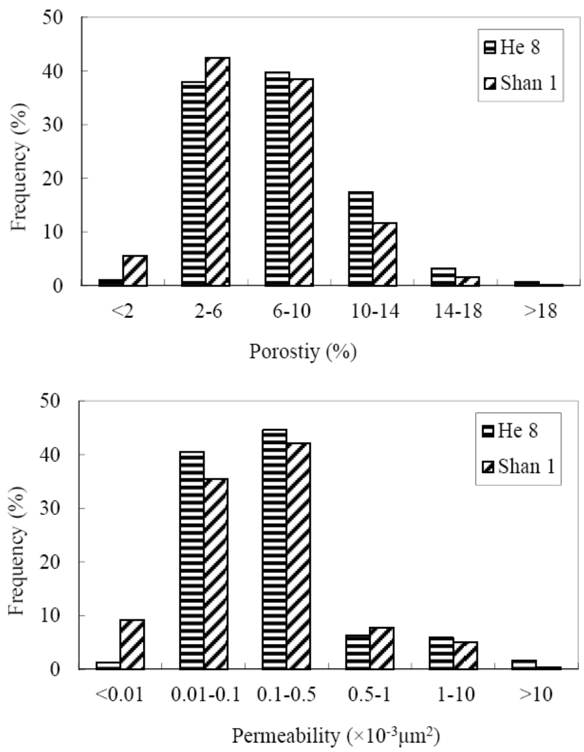

Fig. 3. Frequency of porosity and permeability of the tight sandstone in Sulige gasfield, Ordos Basin.

forming mechanism because the gas migration by diffusion does not depend on conduit systems. The Shanbei slop is characterized by the weak tectonic activities and undeveloped conduit systems (Ma, 2004; Xiao et al., 2005), which is necessary for forming the gas reservoirs by diffusion in the Shanbei slop.

3.2 High geothermal field

Diffusion coefficient, as a major factor controlling the diffusive rate, is strongly influenced by temperature. We measured the methane diffusion coefficient on different temperature and pressure in the tight sandstone of Sulige gasfield (Fig. 2). The results show that with the increasing temperature, diffusion coefficient increases exponentially, which has been certified by other authors (Krooss and Leythauser, 1988, Liu et al., 2012). Three thermal events occurred in the Ordos Basin and the intensive thermal event at the end of Early Cretaceous resulted that the paleotemperature gradient in that time (3.3-4.5 ℃/100m) was much higher than that at present (2.8 ℃/100m) (Ren, 1995). Therefore, the gas diffusion coefficients at the end of Early Cretaceous were about ten times higher than that at present, which is good for gas diffusion in the Upper Paleozoic tight sandstone reservoirs.

3.3 Low porosity and permeability reservoir rocks

The throat radius is fairly small in the low porosity and permeability reservoir rocks, resulting in high capillary resistance, which prevents the gas expulsion from source rocks and gas migration in reservoir rocks by Darcy flow. The Sulige gasfield reservoir rocks are dominated by low porosity (mainly in 2-6%) and low permeability (mainly in 0.01-0.5 mD) sandstones (Fig. 3). The capillary resistance is higher than the driving forces of Darcy flow, which results that the diffusion can be an alternate reservoir-

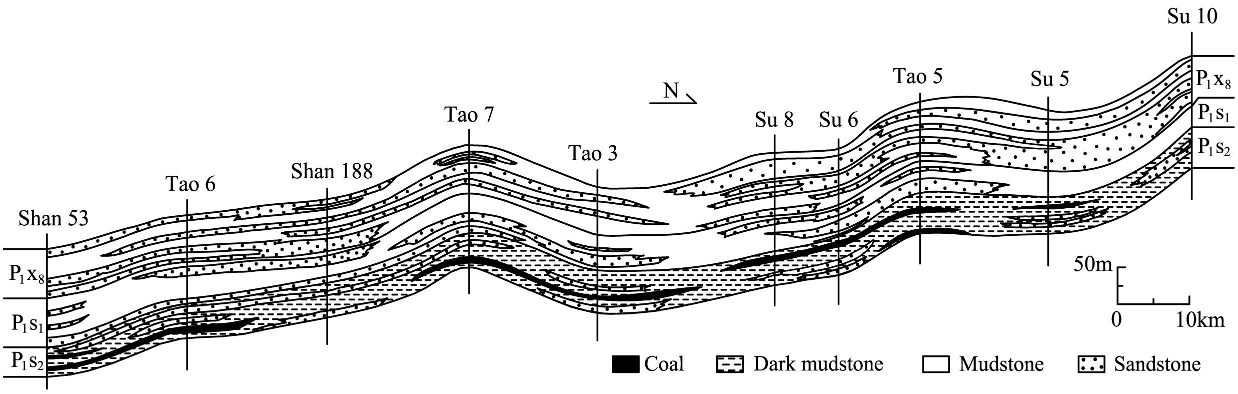

Fig. 4. Types of source-reservoir-cap rock assemblage in Sulige gasfield, Ordos Basin.

forming mechanism in the Upper Paleozoic tight gas reservoirs in the Ordos Basin.

3.4 Favorable source-reservoir-cap rock assemblage

The gas diffusion coefficient for sandstones is larger than that for mudstones mainly due to the differences of porosity, permeability and clay content between them, which indicates that the types of source-reservoir-cap rock assemblage could control the amount of gas diffusion in the reservoir rocks. There are two types of source-reservoir-cap rock assemblage in the Upper Paleozoic tight sandstone gas reservoirs: (a) reservoir rocks in source rocks, and (b) reservoir rocks directly overlying source rocks (Fig. 4). The first type is more favorable for forming the gas reservoirs by diffusion, since gases can diffuse into the sandstone lens of the source rocks from all directions. The second type is also a good assemblage because gases can diffuse into the reservoir rocks overlying the source rocks broadly. Furthermore, the thick mudstones of the Lower Permian Shangshihezi Formation with a stable distribution and excellent sealing ability can sharply reduce the amount of diffusive dissipation, which makes large amounts of gases accumulated in the reservoirs rocks due to the difference of diffusive volumes through the reservoir rocks and the cap rocks.

4 Conclusions

Diffusion is an important reservoir-forming mechanism in the Upper Paleozoic tight sandstone gas reservoirs in Sulige gasfield, Ordos Basin. The favorable geological conditions for gas accumulation by diffusion are weak tectonic activities, high geothermal field, low porosity and permeability reservoir rocks and favorable source-reservoir -cap rock assemblage.

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