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China organic-rich shale geologic features and special shale gas production issues

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ABSTRACT

The depositional environment of organic-rich shale and the related tectonic evolution in China are rather different from those in North America. In China, organic-rich shale is not only deposited in marine environment, but also in non-marine environment: marine-continental transitional environment and lacustrine environment. Through analyzing large amount of outcrops and well cores, the geologic features of organic-rich shale, including mineral composition, organic matter richness and type, and lithology stratigraphy, were analyzed, indicating very special characteristics. Meanwhile, the more complex and active tectonic movements in China lead to strong deformation and erosion of organic-rich shale, well-development of fractures and faults, and higher thermal maturity and serious heterogeneity. Co-existence of shale gas, tight sand gas, and coal bed methane (CBM) proposes a new topic: whether it is possible to co-produce these gases to reduce cost. Based on the geologic features, the primary production issues of shale gas in China were discussed with suggestions.

1. Introduction

Organic-rich shale, including mudstone and shale, was conventionally considered as source rock of hydrocarbon in sedimentary basins. Even though geologists observed natural gas in organic-rich shale long ago (e.g. Devonian Dunkirk shale in the Appalachian basin in 1982 in USA and well Wei5 in Sichuan basin in 1966 in China), the extremely low permeability (nano-level) in matrix makes it hard to produce economical oil and gas flow to the well borehole (Wang and Carr, 2012). Over the past decade, benefiting from innovative technology, horizontal drilling and hydraulic fracturing, and improved integration of geosciences and engineering, shale gas production has been increased rapidly in North America (EIA, 2012). Opportunities for increased shale gas production appear to be global. As investigated by Ministry of Land and Resources of People's Republic of China in 2012, the recoverable shale gas reserve is up to 25.08×10^{12} m^3 in the land area of China (Zhang et al., 2012a).

Organic-rich shale is not only deposited in marine environment, but also in non-marine environment: marine-continental transitional environment and continental environment (mostly lacustrine facies) in China (Zhang et al., 2008; Zou et al., 2011). Distinct from North America, marine organic-rich shale contains only 1/3 of all recoverable shale gas resource, and about 2/3 shale gas was also generated and stored in marine-continental transitional facies and continental facies (Zhang et al., 2012a). The marine shale gas reservoirs were primarily distributed in Paleozoic formations in Yangtze Platform and Tarim basin, while the continental and marine-continental transitional shale reservoirs were distributed in Mesozoic and early Cenozoic formations of basins in North China plate, basins in Northwest China and Sichuan basin. The different types of depositional environments strongly affect the lithology stratigraphy, mineral composition, and organic matter type and organic-rich shale spatial distribution. It is more difficult to produce shale gas from non-marine shale because of the higher clay content, higher ratio of free to adsorbed gas, more interlayers and more serious heterogeneity of shale gas reservoirs. As for the marine shale, even though deposited in the similar environments to North America, the more complex tectonic evolution increases the difficulties to identify the sweet spots of shale gas in China (Ju et al., 2011; Cai et al., 2013; Fang et al., 2013; Guo and Liu, 2013; Zhang et al., 2013a).

In addition, water shortage, as a serious problem in many shale gas basins in China, should be overcome through developing new

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fracturing fluid system (Hu and Xu, 2013). Severely undulating surface, pore development of infrastructure (e.g. roads), and lack of gas pipelines increase the difficulties to produce shale gas in China. It is significant to understand the geologic characteristics of organic-rich shale, their effects on shale gas production, and the special production problems of shale gas in China. Therefore, in this paper, we will analyze the primary features of shale gas reservoirs, including the spatial distribution, depositional environments, mineral composition, organic matter type, richness, and maturation. The special challenges of horizontal well and hydraulic fracturing are discussed with suggestions.

2. The major organic-rich shale in China

Reported by Oil & Gas Survey, China Geological Survey, China has drilled 129 wells related to shale gas from 2009 to 2012, including 46 vertical investigation wells, 55 vertical exploratory wells, and 28 horizontal assessment wells. The production of shale gas is about 0.25×10^{12}–0.30×10^{12} m^3 in 2012 and is up to over 2×10^{12} m^3 in 2013. These shale gas wells, conventional wells penetrating organic-rich shale, and a great number of outcrops provide the basic information to investigate the basic properties of organic-rich shale and their distribution (Fig. 1).

Organic-rich shale deposited before Pre-Cambrian was predominantly metamorphosed, except the Doushantuo shale in upper and middle Yangtze area (Table 1). Organic-rich shales of early Paleozoic were preserved in Yangtze area and Tarim basin (Fig. 1), and all of these shales were deposited in marine facies (Table 1), primarily in the shelf of carbonate platform. Qiongzhusi shale of Lower Cambrian, Wufeng shale of Upper Ordovician, and Longmaxi shale of Lower Silurian are the most promising shale gas reservoirs in South China (Table 1). The average thickness of Qiongzhusi shale is approximately 100 m, covering an area of 30×10^4–50×10^4 km^2 (Zou et al., 2011). The Wufeng–Longmaxi shale, covering most of the Yangtze area, possesses the thickness up to 120 m. Several horizontal wells targeting Qiongzhusi and Wufeng–Longmaxi shales have high initial production rate of shale gas. For example, the horizontal well Yang201-H2 is up to 43×10^4 m^3 per day at the beginning. In Tarim basin, Yuertusi shale and Saergan shale are the potential shale gas plays (Table 1). The primary characteristics of organic-rich shale in China are listed in Table 1, including thickness, total organic carbon (TOC) content, kerogen reflection (R_o), organic matter (OM) type, distribution area, and depositional environment.

During late Paleozoic, the development of organic-rich shale in North China plate became more important (Fig. 1). For example, the coal-bearing organic-rich shale in Benxi group and Taiyuan group of Carboniferous and Shanxi group of Permian were deposited in the whole North China plate, and were primarily preserved in Ordos basin, Qinshui basin, and southern North China plate (Fig. 1). Their depositional environment has been interpreted as marine-continental transitional facies. The total thickness of the three organic-rich shales ranges from 30 m to 180 m in the Ordos basin. Another marine-continental transitional organic-rich shale, Longtan shale of middle Permian, is widely distributed in Yangtze area. The Junggar basin developed three kinds of organic-rich shales during late Paleozoic, including

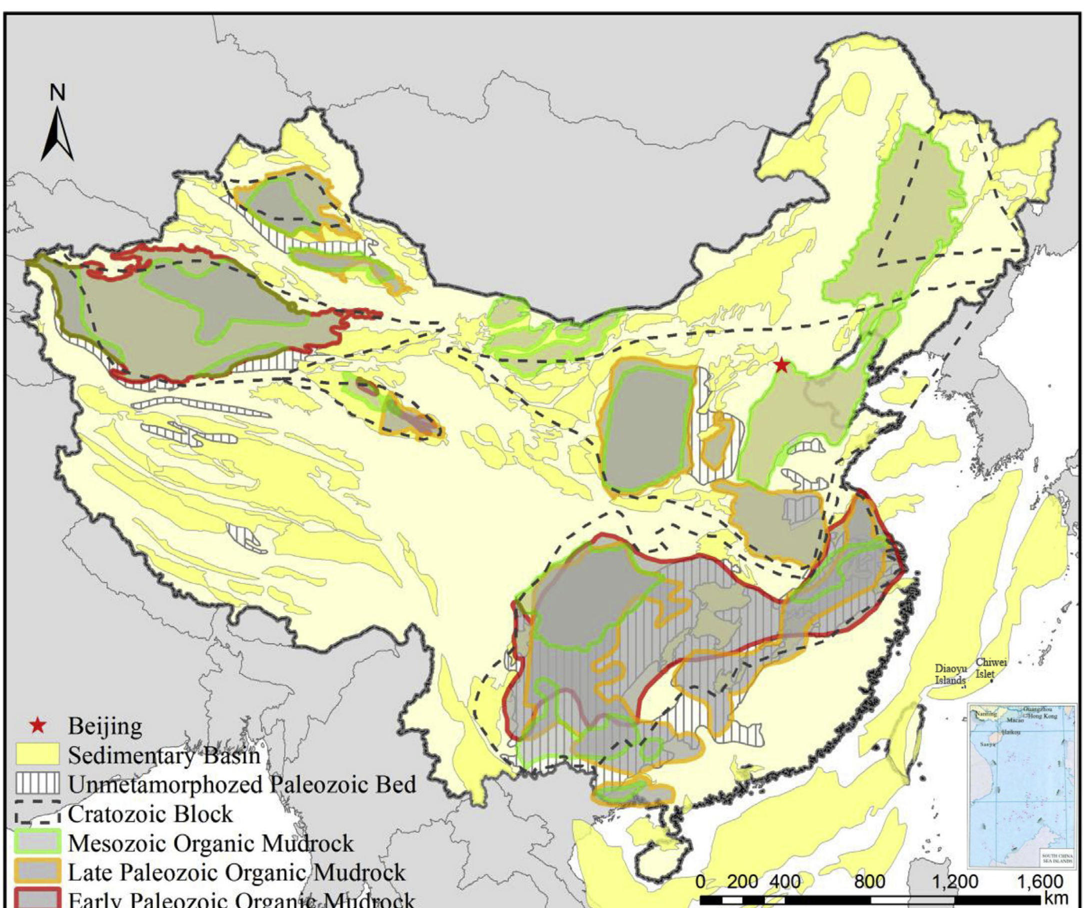

Fig. 1. The distribution of major organic-rich shale in the land area of China.