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Research paper

Properties and shale oil potential of saline lacustrine shales in the Qianjiang Depression, Jianghan Basin, China

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ABSTRACT

The geochemical and petrographic characteristics of saline lacustrine shales from the Qianjiang Formation, Jianghan Basin were investigated by organic geochemical analysis, X-ray diffraction (XRD), scanning electron microscopy (SEM) and low pressure nitrogen adsorption analysis. The results indicate that: the saline lacustrine shales of Eq3 member with high oil content are characterized by type I and type II oil-prone kerogen, variable TOC contents (1.0–10.0 wt%) and an early-maturity stage (R_o ranges between 0.41 and 0.76%). The mineral compositions of Eq3 saline shale show strong heterogeneity: brittle intervals with high contents of quartz and carbonate are frequently alternated with ductile intervals with high glauberite and clay contents. This combination might be beneficial for oil accumulation, but may cause significant challenges for the hydraulic stimulation strategy and long-term production of shale oil. The interparticle pores and intraparticle pores dominate the pore system of Eq3 shale, and organic matter hosted pores are absent. Widely distributed fractures, especially tectonic fractures, might play a key role in hydrocarbon migration and accumulation. The pore network is contributed to by both large size inorganic pores and abundant micro-factures, leading to a relatively high porosity (2.8–30.6%) and permeability (0.045–6.27 md) within the saline shale reservoir, which could enhance the flow ability and storage capacity of oil. The oil content ($S_1 \times 100$/TOC, mg HC/g TOC and S_1, mg HC/g rock) and brittleness data demonstrate that the $Eq3^{3x}$ section has both great potential for being a producible oil resource and hydraulic fracturing. Considering the hydrocarbon generation efficiency and properties of oil, the mature shale of Eq3 in the subsidence center of the Qianjiang Depression would be the most favorable zone for shale oil exploitation.

1. Introduction

Shale oil and gas is currently a hot topic worldwide (Jarvie et al., 2007; Pollastro, 2007; Martini et al., 2008; Ross and Bustin, 2008; Ambrose et al., 2010). The success of shale gas in North America has greatly promoted the activities of shale gas exploration and development in China (Zou et al., 2010; Chen et al., 2011; Hao and Zou, 2013; Hou et al., 2014; Tian et al., 2013). Several economically producing shale gas wells have been drilled in the Upper Ordovician and Lower Silurian shale formations in the Sichuan Basin, southern China (Guo and Zhang, 2014; Wang et al., 2015a,b). The highly mature Paleozoic marine shales are locally distributed, while the less mature Mesozoic to Cenozoic continental shales are more widespread in China. Most of the shale oils produced in China are from the continental shales (Zhu et al., 2005; Ning, 2008; Zou et al., 2010; Zhang et al., 2012a, 2012b; Er et al., 2013). The shale oil resource is approximately 30×10^8-60×10^8 t according to the preliminary prediction (Zou et al., 2010; Zou et al., 2013). A significant amount of oil flows within shales or fractured shale reservoirs have been discovered in the rift basins of eastern China and the foreland basins of western China (Zhu et al., 2005; Ning, 2008). Wide investigations of Chinese shale oil and gas reservoirs have been carried out in the Bohai Bay, Nanxiang Basin, Jianghan Basin, Ordos Basin, Songliao Basin, Sichuan and Junggar Basin (Zhang et al., 2012a, 2012b; Er et al., 2013). Shale oil is far more costly and difficult to extract than shale gas and conventional oil or gas because of the high density, high viscosity and tight reservoir

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properties. With the advancement of horizontal drilling and hydraulic fracturing technology, the lacustrine shales could potentially play an extremely important role in oil production in the future (Zhang et al., 2014; Tang et al., 2015).

Shales deposited in saline basins and interbedded with carbonates, sulfates or chlorates, are regarded as important hydrocarbon source rocks and have been studied widely (Peters et al., 1996; Grice et al., 1998; Jin et al., 2008; Cai, 2012). Previous studies indicate that most of the continental organic-rich shales have close relationships with the saline lacustrine basins or the salification stage of freshwater basins (Zhang et al., 1998; Zheng and Liu, 1999; Zhu et al., 2005; Jin and Zhu, 2006; Liu et al., 2009; Grosjean et al., 2009). Compared with shales deposited in freshwater basins, the saline lacustrine shales are characterized by a higher capacity of hydrocarbon generation, accumulation and preservation, earlier hydrocarbon generation-expulsion and higher hydrocarbon conversion rates (Lewan and Ruble, 2002; Manzi et al., 2007; Jin et al., 2008; Cai, 2012). The Upper Eocene Qianjiang Formation in the Qianjiang Depression, Jianghan Basin was deposited in a typical saline sedimentary environment. Due to the excellent sealing capacity, the sheet-like salts prevent the vertical movement of hydrocarbons; therefore, lateral migration is the major conduit for the conventional reservoirs. Thus, much of the hydrocarbon resources are still retained in the shales, resulting broadly in low hydrocarbon abundance in the conventional sandstone reservoirs of the Qianjiang Depression (Fang, 2002; Tong and Lu, 2006). As the most important oil-bearing structure in the Qianjiang Depression, the Wangchang anticline overlies the primary source rocks (Dai and Pan, 1984; Jiang, 1985). Thus, the oil can migrate easily into the overlying fractured reservoirs formed by tectonic compression,

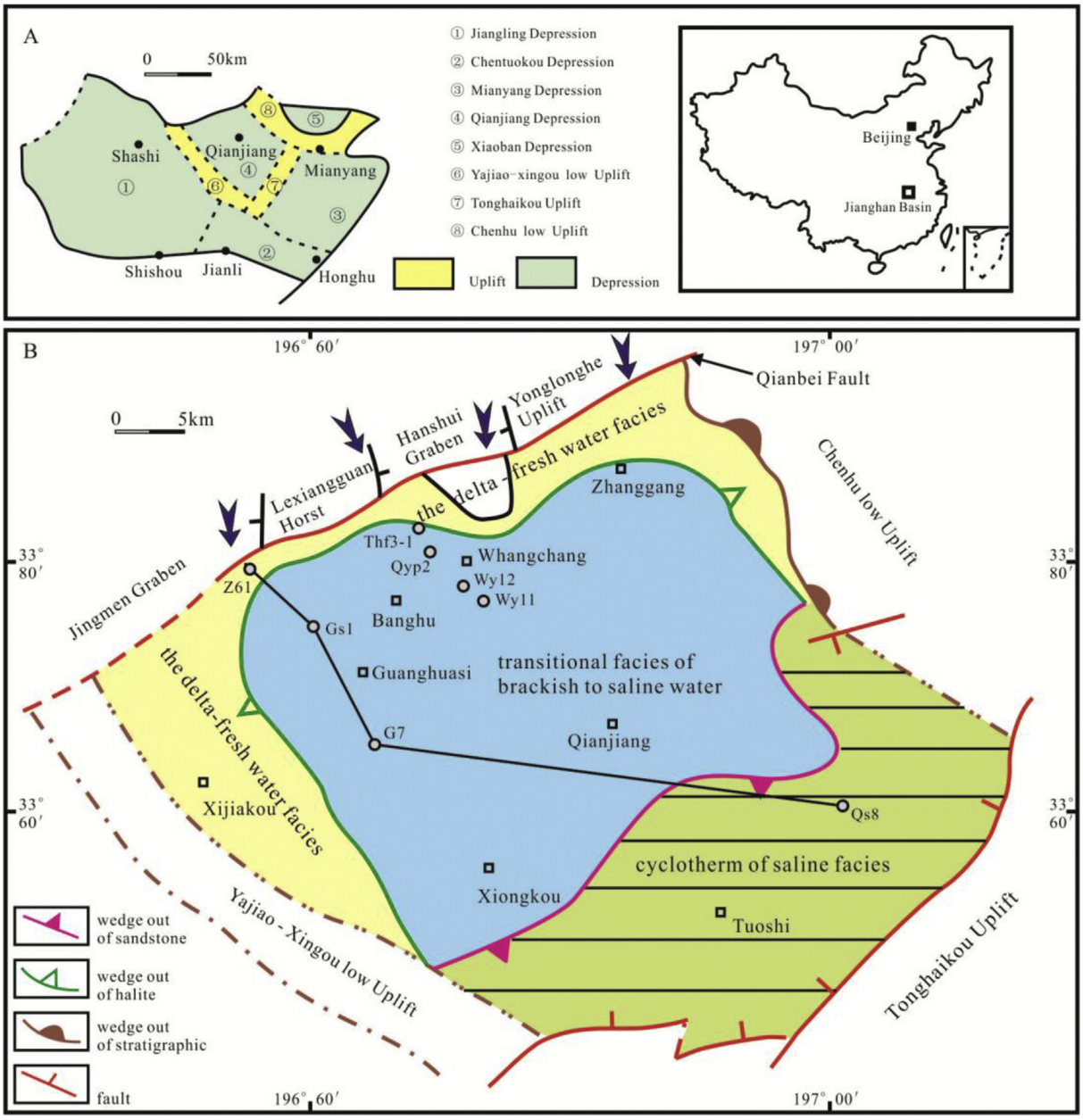

Fig. 1. (A) The location of the Qianjiang Depression in Jianghan Basin. (B) The sedimentary facies division of Qianjiang Depression and the location of sampling wells (modified after Zhang et al., 2005; Tong and Lu, 2006; Chen, 2007).