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Geological and geochemical characterization of lacustrine shale, a case study of Lower Jurassic Badaowan shale in the Junggar Basin, Northwest China

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ABSTRACT

Organic-rich shale deposited in a lacustrine environment is well developed in China and considered to contain a large amount of shale hydrocarbon resources. The Lower Jurassic Badaowan shale in the Junggar Basin is a typical lacustrine deposit that is regarded as the most significant source of natural gas. This study describes the geological and geochemical features of Lower Jurassic Badaowan shale and investigates its hydrocarbon resource. The Badaowan shale has fair to good hydrocarbon potential, and contains dominantly type III gas-prone organic matter (OM). Its thermal maturity ranges from immature to gas window (R_o, 0.5%–1.2%) and increases from north to south. However, In comparison with that of typical marine gas shales, the thermal maturity of Badaowan shale is lower at similar depths. X-ray diffraction (XRD) analyses show that lacustrine shale is fairly homogeneous and dominated by clay and brittle minerals. The clay minerals are dominated by illite and mixed illite/smectite. Observation made with a scanning electron microscopy (SEM) shows that intra particle (IntraP) pores and inter particle (InterP) pores are well developed, OM pores appears rarely due to its relatively low thermal maturity. A large thermogenic gas resource may occur in the southern basin. Unfortunately, potential gas shale in the southern Junggar basin is buried deeper than 6000 m, high costs and reduced permeability will make future exploration and development risky. Generally, the low thermal maturity and high clay content of Badaowan shale result in challenges to successful shale gas production.

1. Introduction

Shale gas resources have become a significant target in natural gas exploration around the world because of the very successful shale gas production in the United States (Arthur et al., 2008; Bowker, 2007; Curtis, 2002; Horsfield and Schulz, 2012). Success in producing gas from marine shales has renewed interest in efforts to attempt to produce gas from lacustrine organic-rich shales (Guo et al., 2014a; Hao et al., 2013; Ji et al., 2014; Katz and Lin, 2014; Yang et al., 2015).

In China, there are multiple lacustrine organic-rich shales that developed between the Precambrian to the Tertiary in age. These lacustrine deposits are the main sources for large oil and gas fields and are expected to have a huge potential of shale gas and shale oil potential (Hao et al., 2013; Zou et al., 2010). Recently, many studies have been conducted to characterize these lacustrine shales, and a considerable amount of oil and gas have been obtained from shale intervals. For example, in the Ordos Basin, some vertical wells have been drilled to Upper Triassic organic-rich shale intervals and two to five tons of oil on average and 1000–3000 m^3 of natural gas have been produced per day by fracturing (Tang et al., 2014).

Junggar Basin, one of the most important petroleum bearing basins in China, has been initially estimated to have a large potential of shale gas and oil resources (Jia et al., 2012; Jiang et al., 2012; Pang et al., 2011; Stevens et al., 2013; Zou et al., 2011). As pointed by Stevens et al. (2013), the Permian and Triassic are the most favorable strata for shale gas and shale oil accumulation. An initial assessment conducted by EIA (2013) shows that the Permian is estimated to have risked original gas in place (OGIP) of 172 Tcf, and original oil in place (OOIP) of 109 BBO. For the Triassic, OGIP

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and OOIP are 187 Tcf and 134 BBO respectively. For the Jurassic, it has been proved to be a source for several natural gas fields (e.g., the Hutubi, Mosuowan and Mahe gas fields; see Cao et al., 2012; Hu et al., 2010; Li et al., 2009a). In particular, Lower Jurassic Badaowan shale, which is a typical lacustrine deposit comprising very thick and widely distributed organic-rich shale (Fu et al., 1996; Li et al., 2009a; Liu et al., 2002), is considered to have a large potential of shale gas resources. Therefore, a detailed investigation of Badaowan shale is needed.

In this study, we characterized the geological and geochemical features of Badaowan shale. In addition, we conducted a preliminary investigation into the shale gas potential of lacustrine shale and discussed the major risks in shale gas exploration and production based on the results of geological and geochemical analyses.

2. Geological setting

The Junggar Basin is located in northwestern China, with an area of 13 × 10^4 km^2. It is one of the most important oil and natural gas provinces in China. The Junggar Basin is an upper Paleozoic, Mesozoic, and Cenozoic basin superimposed at the junction of the Kazakhstan Block, the Siberia Block, and the Tarim Block (Jin et al., 2008). The Delun, Halaalate, and Zhayier Mountains form the northwest boundary of the Junggar Basin, which reaches the Yilinheibiergen Mountains in the southwest, the Qinggelidi and Kelameili Mountains in the northeast and the Bogeda Mountains in the southeast. Tectonically, the basin can be divided into the following six first-order structural units: the Wulungu Depression, West Super-uplift, East Super-uplift, Southern Depression, Luliang Super-uplift and Central Depression (Fig. 1).

The Junggar Basin contains upper Paleozoic to Cenozoic strata (Fig. 2) and several hydrocarbon source rocks. In the national third-round assessment of hydrocarbon resources (Wang et al., 2000), Junggar Basin was estimated to have a large amount of natural gas resources which mainly originated from the Carboniferous, Permian and Jurassic strata (Jia, 2005; Li and Liu, 2005; Yu et al., 2006; Zhao et al., 2009).

3. Database and experimental methods

3.1. Organic geochemistry

In this study, 93 Rock-Eval pyrolysis (TOC, S_1, S_2 and T_{max}; Table 1) and 46 R_o (vitrinite reflectance; Table 2) experimental data of core samples were used to determine the geochemical characteristics of Badaowan shale. The data was provided by the Xinjiang Oilfield Company of PetroChina. Nine core samples from six wells were selected for mineral composition and microscopic pores analyses. The locations of the sampled wells are shown in Fig. 1.

3.2. X-ray diffraction (XRD)

X-ray diffraction (XRD) was used to identify the mineral composition of nine core samples, and this analysis was performed at Bangda New Technology co. ltd, Renqiu, China. The experimental temperature and humidity was 24 °C and 35%, respectively. Crushed samples (< 200 μm) were mixed with ethanol, hand ground and then smear mounted on glass slides for X-ray diffraction analysis. The measurements were done using a Bruker D8-Discover Advance X-ray diffractometer with Cu Kα-radiation (45 kV, 35 mA) over the angular range of 2–60° (2θ) at scan rates of 2°/min (2θ). Quantitative phase analysis was performed by Rietveld refinement, with customized clay mineral structure models (Ufer et al., 2008).

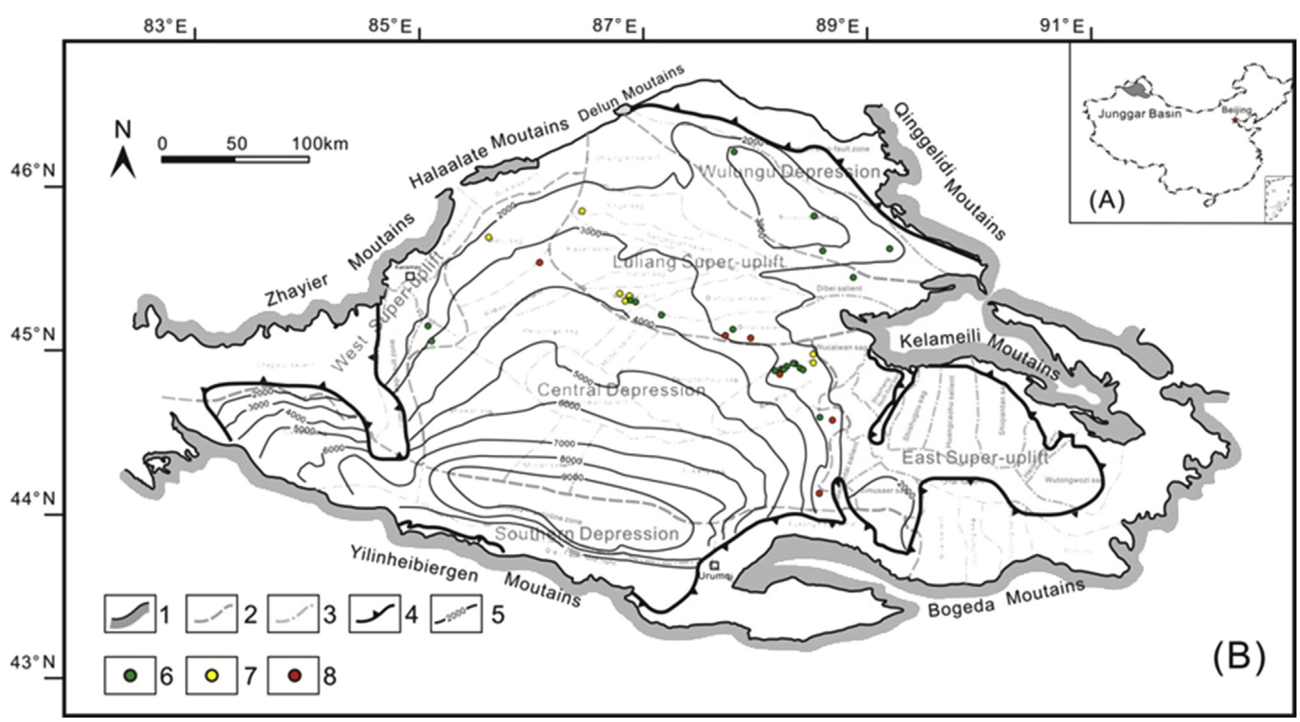

Fig. 1. (A) The location of the Junggar Basin in northwestern China. (B) A map showing the geologic setting and main structural elements of the Junggar Basin. 1 = basin boundary; 2 = first-order structural unit boundary; 3 = secondary-order structural unit boundary; 4 = pinch-out boundary; 5 = structure contour on top of the Badaowan shale (contour values are in meter); 6 = TOC and Rock-Eval pyrolysis sampled well location; 7 = R_o sampled well location; 8 = XRD and SEM sampled well location.