Journal of Natural Gas Science and Engineering 28 (2016) 639–650

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Shale gas potential of Lower Permian marine-continental transitional black shales in the Southern North China Basin, central China: Characterization of organic geochemistry

Wei Dang [a, b], Jinchuan Zhang [a, b, *], Xuan Tang [a, b], Qian Chen [a, b], Shuangbiao Han [a, b], Zhongming Li [c], Xiaorui Du [a, b], Xiaoliang Wei [a, b], Mingqiang Zhang [a, b], Jing Liu [d], Jianlong Peng [a, b], Zhenglin Huang [a, b]

[a] Key Laboratory of Shale Gas Exploration and Evaluation, Ministry of Land and Resources, China University of Geosciences, Beijing 100083, China
[b] School of Energy Resources, China University of Geosciences, Beijing 100083, China
[c] Henan Institute of Geological Survey, Zhengzhou 450000, China
[d] School of Earth and Space Sciences, Peking University, Beijing 100871, China

ARTICLE INFO

Article history:
Received 15 September 2015
Received in revised form
18 December 2015
Accepted 20 December 2015
Available online 23 December 2015

Keywords:
Shale gas
Organic geochemistry
Hydrocarbon generative potential
Transitional shale
Southern North China Basin
North China

ABSTRACT

With the purpose of characterizing the organic geochemistry and investigating the shale gas potential, we applied multiple methods, including quantifying organic matter richness, polarizing microscope observations, maceral composition analysis, kerogen stable carbon isotope analysis, vitrinite reflectance analysis, and Rock-Eval pyrolysis were performed on black shale samples from the Lower Permian Shanxi and Taiyuan formations in the Mouye-1 well of the Southern North China Basin. The results indicate that the average total organic carbon (TOC_{pd}) content at the present time is 1.73% and 2.41% for Shanxi and Taiyuan shale samples, respectively. The microscopic distribution of organic matter includes scattered types and local enrichment types, as well as layered enrichment types. These types were revealed by polarizing microscope observations and exhibit an excellent correlation with the TOC content of shale samples. Based on maceral compositions and kerogen stable carbon isotopes, organic matter in Shanxi and Taiyuan shales is characterized by gas-prone, inertinite-dominated type III kerogen. The thermal maturity, as indicated by measuring vitrinite reflectance (3.2–3.6%R_o), suggests that shale samples from Shanxi and Taiyuan formation in the Mouye-1 well have evolved far into the metagenesis stage, and no significant amounts of hydrocarbons can be generated. The remaining hydrocarbon generative potential, S2 (0.02–0.77 mg HC/g Rock), which was determined by Rock-Eval pyrolysis, also supports this conclusion. Additionally, the original total organic carbon (TOC_o) content and hydrocarbon generative potential ($S2_o$) were reconstructed based on Jarvie's equations for these thermally over-mature shales; this reconstruction indicated poor to fair original source rock potentials based on the correlations of TOC_o and $S2_o$. Furthermore, the total volume of gas generated during thermal maturation was calculated using a conversion formula based on molar mass and resulted in a yield of 5.69 cm^3/g Rock and 3.54 cm^3/g Rock for Shanxi and Taiyuan shale samples, respectively. Overall, inertinite-dominated maceral compositions of kerogen with extremely high thermal maturity can have a negative effect on the gas potential of shale in the Southern North China Basin.

1. Introduction

The remarkable success of shale gas development in North America has aroused a shale gas exploration boom and encouraged investigation into the gas potential of shales worldwide (Bowker, 2007; Chalmers and Bustin, 2007; Curtis, 2002; Hill et al., 2004; Jarvie et al., 2007; Nie and Zhang, 2012; Tang et al., 2014; Zhang

* Corresponding author. School of Energy Resources, China University of Geosciences, Beijing 100083, China.
E-mail addresses: dangwei09@cugb.edu.cn (W. Dang), Zhangjc@cugb.edu.cn (J. Zhang), tangxuan@cugb.edu.cn (X. Tang), 465062881@qq.com (Q. Chen), 627173080@qq.com (S. Han), 646656313@qq.com (Z. Li), 653005823@qq.com (X. Du), 545688284@qq.com (X. Wei), zmingq@qq.com (M. Zhang), liujingeva@pku.edu.cn (J. Liu), 349176405@qq.com (J. Peng), 1158482843@qq.com (Z. Huang).

http://dx.doi.org/10.1016/j.jngse.2015.12.035
1875-5100/

et al., 2009). To develop clean energy, Chinese scientific research institutions and geologists have been studying the formation and distribution of black (organic matter-rich) shale nationwide since 2008. In China, black shales from three origins, including marine, marine-terrestrial transitional, and terrestrial origins, were found ranging from Precambrian to Cenozoic. Widespread Cambrian and Silurian marine shales were found in southern China, while Carboniferous and Permian transitional shales, as well as Triassic to Paleocene lacustrine shales, were found in central and northern China, respectively (Zhang et al., 2009; Zou et al., 2010). By the end of 2014, research into and exploration of marine and lacustrine shales were already underway in different parts of China (e.g., Sichuan Basin, Upper Yangtze Platform; Middle Yangtze Platform; Ordos Basin; Bohai Bay Basin) (Nie and Zhang, 2012; Tang et al., 2014; Wang et al., 2012; Zhang et al., 2010, 2008a). Most excitingly, China successfully built the first marine shale gas field in the Fuling, Sichuan Basin in 2014, which made China the third country to achieve commercial development of shale gas. Compared to the development of marine and lacustrine shale gases, however, few studies have been performed on Upper Paleozoic transitional shales, which are widely distributed across the nation and are considered to possess large potentials for shale gas exploration (Zhang et al., 2009, 2008b; Zou et al., 2010).

The Southern North China Basin (SNCB), located in the central region of China, is a typical transitional coal-bearing basin with a total area of 15×10^4 km^2 and was identified in 2012 as a promising area in China for transitional shale gas investigation by the Ministry of Land and Resources (Fig. 1). Previous studies suggest that although Several geological features can differ greatly between marine and transitional shales (Ju et al., 2014), the shales of the Lower Permian Shanxi and Taiyuan formation in this area still may serve as source rocks for conventional oil and gas (Wu et al., 1992; Xu et al., 2004; Zhang, 1990), as well as a potential promising target for shale gas exploration due to the large gross thickness of shale intervals, relative high TOC content, presence of gas-prone kerogen, and moderate thermal maturity (Cheng, 2012; Wang et al., 2014, 2015). Additionally, these transitional shales also provide a possibility of co-existence and joint-production of shale gas, tight sand gas and coal bed methane in the same formation (Ju et al., 2014). However, quantitative geological and geochemical information of the shales described in previous studies are primarily based on outcrops, which does not reflect the real characteristics of the shales due of weathering (McCarroll, 1991; Sawyer, 1986). The Mouye-1 well, which was drilled in Zhongmou County in August 2014, was the first well where transitional shale gas potential was investigated in the SNCB (Fig. 1). This investigation revealed the Lower Permian Shanxi and Taiyuan formations to have thicknesses of 89.5 m and 67.5 m, respectively (Fig. 2). Additionally, the full coring of these two formations, as well as on-site gas content measurement in this well, provided opportunities to obtain information necessary for evaluating the transitional shale gas potential in this region.

As such, the primary objective of this study was to characterize the organic geochemical characterization of Shanxi and Taiyuan transitional shales collected from the Mouye-1 well to evaluate shale gas potential (e.g., kerogen type, thermal maturity, present and original organic matter richness, hydrocarbon generative potential). Among the parameters tested, organic matter richness, kerogen type, and thermal maturity are large contributors to the gas generation potential and are key parameters for the evaluation of hydrocarbon potential (Horsfield and Schulz, 2012; Jarvie et al., 2007; Romero and Philp, 2012). Remaining hydrocarbon generative potential (S2, mg HC/g Rock) and hydrogen index (HI, mg HC/g TOC), revealed by Rock-Eval pyrolysis, are also widely used

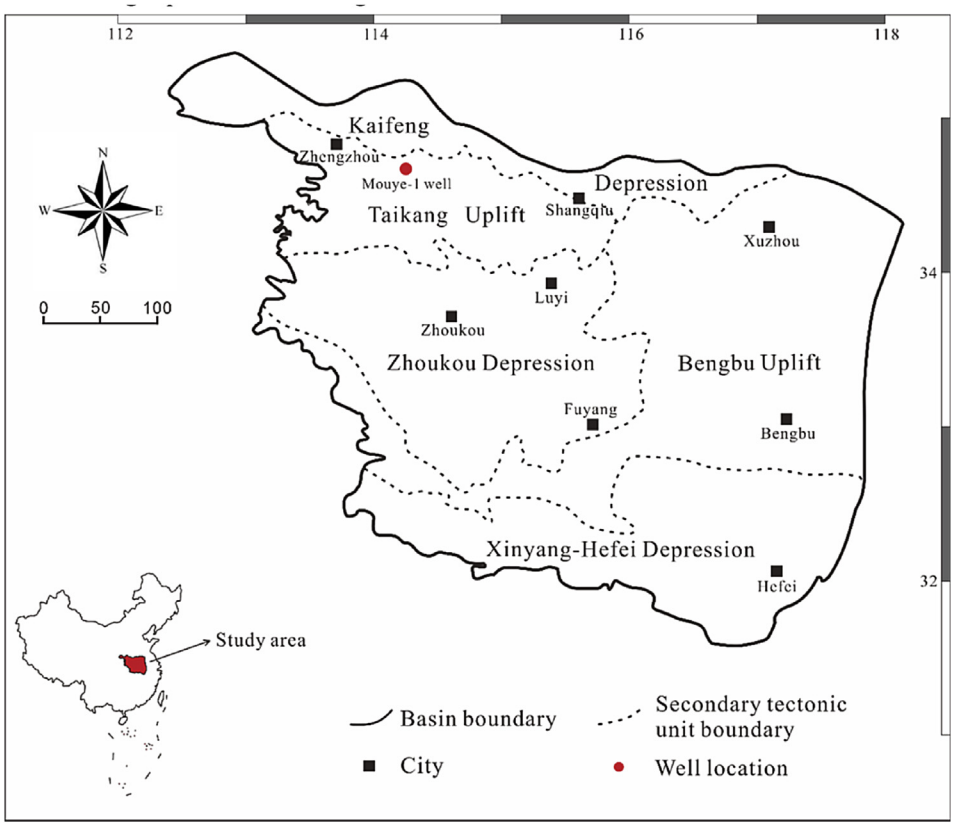

Fig. 1. Simplified structural map of SNCB with investigated well location (modified from Sun, 1996).