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Effect of organic matter on pore structure of mature lacustrine organic-rich shale: A case study of the Triassic Yanchang shale, Ordos Basin, China

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ABSTRACT

The effect of extractable organic matter and solid organic matter on the pore structure of shale from Yangchang Formation in the Ordos Basin, China is investigated in this study. The shale samples were successively crushed, extracted by dichloromethane to remove extractable organic matter, treated by hydrogen peroxide to remove solid organic matter. The porosity, organic and mineralogical characteristic of original, extracted and H_2O_2 treated shale samples were analyzed via low pressure gas adsorption measurement, X-ray diffraction (XRD) and Rock-Eval pyrolysis. Results show that pores in the studied shale were occupied and blocked by extractable organic matter with varying degrees which seriously affect porosity. Pores with small diameter will be preferential occupied and blocked. The plentiful generation of hydrocarbon in organic-rich shale will lead to high fluid pressure in pore which protect pore from compaction during evolution and lead to a higher porosity. This protection mainly act on macropores. Pores in the studied shale were dominated by quartz-related and clay-related pores, and organic matter hosted pore is rare. Solid organic matter content act as a harmful factor to total porosity of studied shale. Firstly, high content of solid organic matter reduce the relative content of quartz and clay minerals then lead to a low total porosity. Secondly, solid organic matter occupied and blocked pores related to quartz and clay minerals.

1. Introduction

Organic-rich shale is important both as a traditional oil shale resource [1,2] and as source rocks for conventional [3] and unconventional oil and gas [4,5]. The Triassic Yanchang Formation in the Ordos Basin has all three attributes, having sourced traditional oil reservoirs [6,7], being considered as a target for production from the mature source rock by hydraulic fracturing [8–10], and occurring near the surface with organic carbon content greater than 10% by weight [11].

Shale pore structure are important factors affecting the shale oil and gas content. The correct understanding of the pore structure of shale is the foundation of shale oil and gas exploration and development [12,13]. Pores are generally classified according to their diameters as micropores (<2 nm), mesopores (2–50 nm), and macropores (>50 nm; [14]). Different from conventional oil and gas reservoirs, the main controlling factor of hydrocarbon reservoir capacity in shale is nanometer pores [12], which are micropores, mesopores and a component of macropores.

Organic matter (OM) in shale is generally thought to the primary factor controlling shale porosity [15–18]. OM in shale can be divided into two parts: extractable organic matter (EOM, or so-called residual bitumen) and solid organic matter (SOM).

EOM can occupy and block the pores in thermally low mature or mature shale then dramatically influence the pore structure [18–23]. Porosity of shale greatly increased after removal of EOM by organic solvent extraction, which is generally agreed in previous studies. However, there is still no agreement on the effect of EOM on pore size distribution of shale. Wei et al. [20] used gas

Abbreviations: TOC, total organic carbon; OM, organic matter; EOM, extractable organic matterextractable organic matter; SOM, solid organic matter; FIB-SEM, focused ion beam scanning electron microscopy; BET, Brunauer–Emmett–Teller (BET) theory; BJH, the Barret, Joyner, and Halenda theory; DFT, density functional theory; D-A, Dubinin-Astakhov theory; PCA, principal component analysis; DCM, dichloromethane.

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adsorption to measure the pore structure before and after removing EOM from shale with various TOC and maturity. The results showed that mesopore volume increase more in extracted shale with higher maturity, whereas the strongest gain in micropore volume is observed at elevated TOC content and highest maturity. Xiong et al. [21] analyzed the pore structure of original and extracted Yanchang shale from the Ordos Basin, China using nitrogen adsorption and argued that the growth of shale porosity after extraction was closely related with pores of >30 nm and <10 nm respectively. Liu et al. [22] investigated the pore structure of Yanchang shale using Soxhlet extraction, focused ion beam scanning electron microscopy (FIB-SEM) and gas adsorption and argued that the pores with diameter of 4 nm were block up by EOM. Pore structure of original and extracted shale from the Upper Permian in the Sichuan Basin, China were investigated using gas adsorption by Pan et al. [23], and the results showed that EOM mainly occupied pores with diameter <5 nm in shale with low maturity, whereas in shale with moderate maturity, pores with diameter of 2–20 nm were occupied by EOM.

The evolution of SOM-hosted pores during thermal maturation has been well studied and been generally regarded as one primary reason for the porosity change during shale evolution [11,15,24,25]. However, study on the effect of SOM on inorganic pores is still less. Kuila et al. [26] investigated pores in organic-rich mudrocks with various maturity before and after OM removal by buffered sodium hypochlorite (NaOCl) treatment using gas adsorption and field emission scanning electron microscopy (FESEM) and argued that OM in the immature mudrocks does not have any evidence of open micro- and fine-scale mesoporosity within OM matrix itself and can partially filled clay-hosted pores. However, the effect of EOM had not been considered in the study of Kuila et al. [26].

Therefore, it is necessary to study the effect of EOM and SOM respectively on the pore structure of organic-rich shale. In the current study, shale from Yangchang Formation in the Ordos Basin, China was utilized, successively crushed, extracted by dichloromethane (DCM) to remove EOM, treated by hydrogen peroxide (H_2O_2) to remove SOM. The original, extracted and H_2O_2 treated shale samples were respectively tested via X-ray diffraction (XRD), Rock-Eval pyrolysis and gas adsorption measurement. The goals were (1) to understand the effect of EOM on pore structure, (2) to research contribution of bulk composition to porosity, and (3) to analyze the effect of SOM on total porosity and inorganic pore structure.

2. Samples and methods

2.1. Samples

32 shale cores from YK-1 well located in the south of the Ordos Basin, China (Fig. 1a) were utilized in this study. The sampling formation is the Upper Triassic Yanchang formation (from Chang-6 to

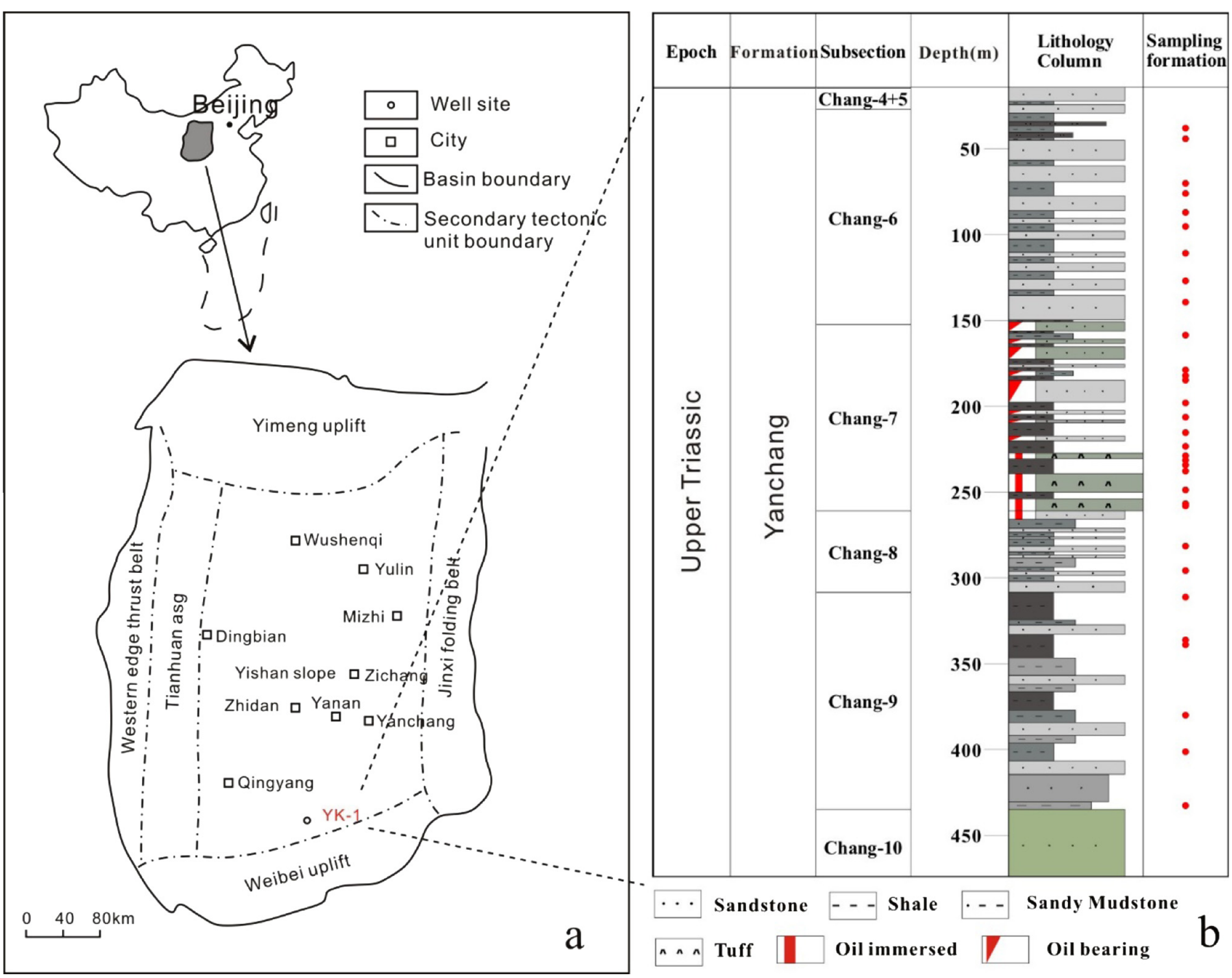

Fig. 1. Location of Ordos Basin and sample well (a) and the lithology column for well YK-1 and sampling formation (b).