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Coal seam porosity and fracture heterogeneity of macrolithotypes in the Hancheng Block, eastern margin, Ordos Basin, China

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ABSTRACT

Heterogeneity in cleats and pore size distribution within coal macrolithotypes (bright, semi-bright, semi-dull, and dull coals, determined from the overall relative luster and percentage of bright components) impact coalbed methane (CBM) extraction. However, few studies have investigated the characteristics of macrolithotypes across multiple length scales. Here, the macrolithotype description was performed for the No. 3, 5, and 11 coal seams in the Hancheng Block of Ordos Basin. The cleats were characterized by optical microscopy and X-ray computed tomography (CT) while pores and their connectivity were determined from mercury intrusion porosimetry, N_2 and CO_2 adsorption, and low field nuclear magnetic resonance (NMR) of water saturated cores evaluated both cleats and pores. The CH_4 adsorption capacity of coal samples scraped from the surface of the macrolithotype layers was also determined. Dull lithotypes (semi-dull and dull) were dominant, followed by bright lithotypes (bright and semi-bright) in these seams. The bright lithotype coal has a higher microfracture density (averaging 339 microcleats per 9 cm^2, μm–mm), better connectivity, and a larger fractal dimension (averaging 1.7) from optical microscopy. The dull lithotype has a lower average microfracture density (272 microcleats per 9 cm^2) and a smaller fractal dimension (~1.6). This higher connectivity observation was consistent with X-ray CT observations and low field NMR of the water saturated cores (and the transition upon water removal from the fractures and larger pores). Also the ease of mercury injection from cores also supported higher connectivity in the bright lithotypes. Both the semi-bright and semi-dull lithotypes have equivalent pore proportions micro- to macropores and good apparent connectivity at the nm–μm scale; despite mineral occlusions. Based on the CH_4 adsorption capacities of the macrolithotypes, the bright coal has the greatest gas adsorption capacity, due to the largest smaller micropores (<2 nm) and a higher specific surface area. These observations aid in understanding the complex behavior observed in CBM extraction and evaluating the impacts of heterogeneity and scale on the degassing behavior.

1. Introduction

Coalbed methane (CBM) supplements the conventional natural gas supply in the United States, Canada, and Australia (Moore, 2012). Significant CBM development has also occurred in the southern Qinshui and in the eastern margin of the Ordos Basins, China (Lv et al., 2012; Zhao et al., 2014, 2015a, 2015b). Improved theoretical rationalization is necessary for Chinese CBM industry development (Xu et al., 2012, 2014). Coal seams are naturally-fractured reservoirs consisting of matrix blocks, where most of the gas is primarily adsorbed within the micropores. The cleat network, that is usually water saturated under in situ conditions, provides the main flow paths for gas and water (Gamson et al., 1996; Chen et al., 2014; Pant et al., 2015). These reservoirs behave very differently from conventional natural gas reservoirs and are impacted by the heterogeneous pore and fracture structure and the physicochemical properties (Ward, 2002; Li et al., 2014; Singh et al., 2015). The macro- and microscopic compositions directly determine CBM reservoir quality and workability, and influence the developmental approach (Tang et al., 2014). Thus, the macrolithotype properties (such as proximate analysis, pore size distribution, and gas adsorption capacity) greatly influence the CBM exploration and development (Diessel, 2007; Li et al., 2012a; Nie et al., 2015).

Compared to conventional carbonate and sandstone reservoirs, the pore size of coal reservoirs is much smaller (nm) (Karacan, 2003; Nelson, 2009). From adsorption and capillary condensation theory, pore and fracture classification systems have been proposed. The Hodot classification system is most widely applied in the Chinese CBM industry (Li et al., 2014), which divides coal pores into micropores (<10 nm in size), transition pores (10–100 nm), mesopores (100–1000 nm), and macropores (>1000 nm) (Hodot, 1966). This differs to

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the International Union of Pure and Applied Chemistry (IUPAC) classification system where micro-, meso-, and macropores have different size classifications (IUPAC, 1972). For bituminous coals, it is the transition pores and micropores that are regarded as absorption pores (<100 nm); these control gas adsorption, desorption, and diffusion. But, the relative abundance of macro- and mesoporosity which are considered of seepage pores (>100 nm) allows for either improved flow: gas laminar/turbulent flow or slow laminar flow, respectively (Shi and Durancan, 2005; Yao et al., 2009; Li et al., 2014).

In comparison to conventional gas reservoirs, coal seams can be extensively naturally fractured (cleated) (Close, 1993; Laubach et al., 1998). These cleats provide the flow pathways for methane out of the coal seam. However, there is considerable complexity and heterogeneity that is not commonly included in modeling efforts. From microscopy, the microfracture frequency and diversity can be classified (A–D) according to Yao and Liu (2009): type A (≥5 μm in width and ≥10 mm in length with good continuity), type B (≥5 μm in width and <10 mm in length comprising dendritic-like fractures), type C (<5 μm in width and ≥300 μm in length), and type D (<5 μm in width and <300 μm in length with poor connectivity).

Coal reservoir characterization is directly affected by pore and fracture distribution (Yao et al., 2009). Usually, microfractures are observed by optical microscopy and scanning electron microscopy (SEM) while mercury intrusion porosimetry (MIP, with a test range of 7.1 nm–500 μm) and N_2 adsorption (with a test range of 1.7–300 nm) are used to determine the pore size distribution (Clarkson and Bustin, 1999a, 1999b; Zou et al.,

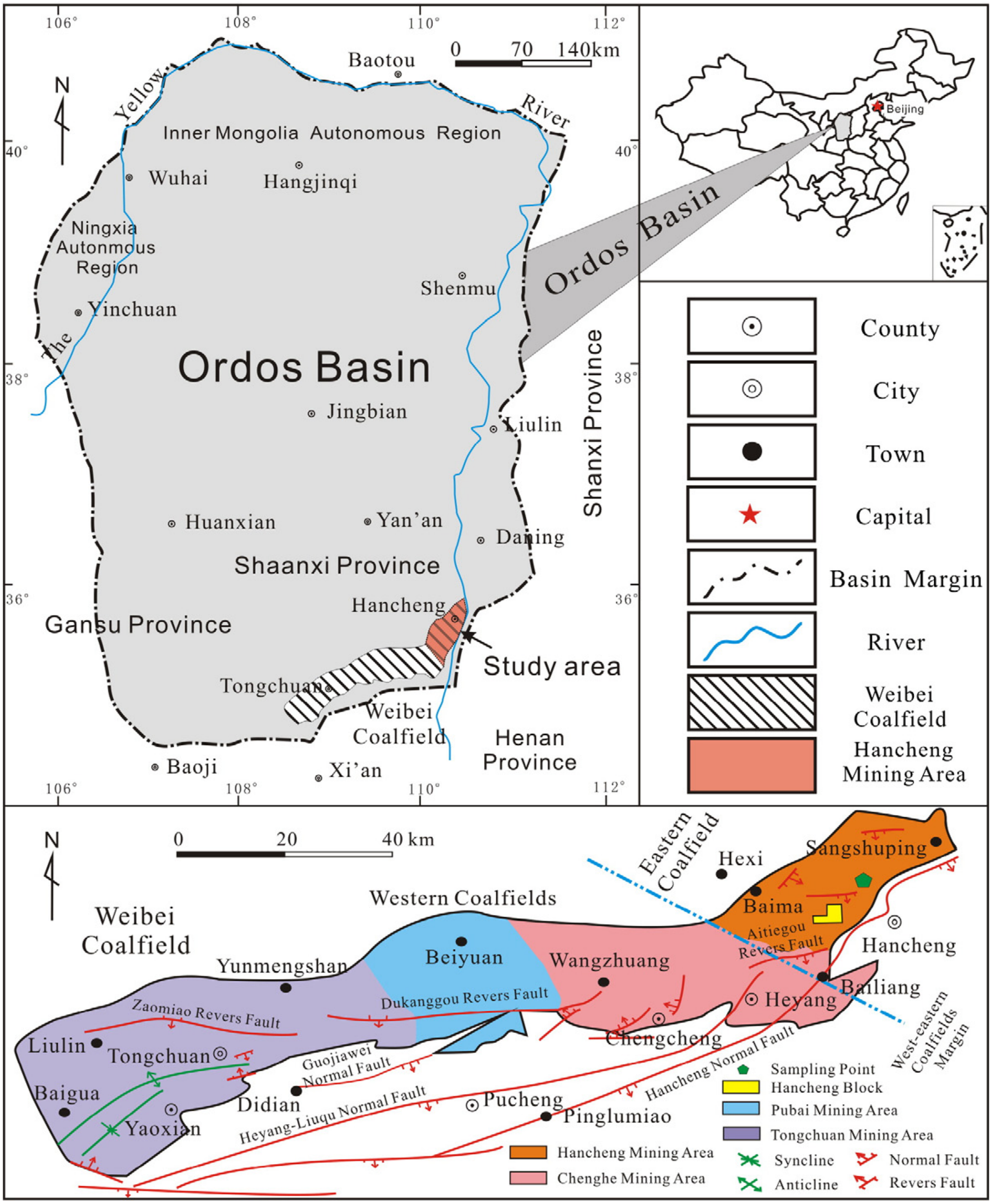

Fig. 1. Map of the Ordos Basin and the position of the Hancheng Block.